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NOMENCLATURE

dB	decibel
EPNdB	effective perceived noise level - decibels
Hz	Hertz - cycles per second
PNL	perceived noise level - decibels
PNLT	perceived noise level tone corrected - decibels
RMS	root mean square
RPM	revolutions per minute
SPL	sound pressure level - decibels
V/STOL	vertical and short take off and landing
α	angle of attack - pitch attitude with respect to horizontal
ips	inches per second

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SUMMARY

The XV-5B V/STOL fan research aircraft was flown at 15.24 meters (50 feet) altitude in conventional jet mode over a microphone array set up at the north end of runway 32L at Moffett Field, California. Noise data measurements were taken for several passes of the aircraft. The flyover data were reduced, corrected, and then compared to data taken during a test in the Ames 40- by 80-foot (12.2 x 24.4 meter) wind tunnel. The data show very good agreement for 1/3 octave band comparisons.

INTRODUCTION

Ames Research Center is actively involved in aircraft noise research. Noise data measurements from scale model research aircraft are being made in the Ames 40- by 80-foot (12.2 x 24.4 meter) wind tunnel, and are being used to predict noise emission from future aircraft. To test the validity of the wind-tunnel measurements, two currently flying research aircraft have been flown over microphone arrays set up on runway 32L at Moffett Field, California. The aircraft were then tested in the Ames 40- by 80-foot wind tunnel using microphone arrays with similar geometry. The data from each test were reduced, analyzed, and compared. Reference 1 reported the results from a propeller type aircraft. This report summarizes the results from the XV-5B fan research aircraft flown in jet mode.

AIRCRAFT AND INSTRUMENTATION

Aircraft

The XV-5B V/STOL fan research aircraft is a three fan, dual gas generator aircraft. Two 1.52 meter (5 foot) diameter lift fans are located in the wings at mid-semispan and one 0.914 meter (3 foot) diameter pitch fan is located in the nose of the aircraft. The fans are tip turbine driven by the exhaust from two J-85-5 General Electric gas generators and are interconnected by ducting. The exhaust from the gas generators can be diverted from the fans by means of valves to allow conventional jet mode flight. The basic airplane has a wing span of 9.09 meters (29.83 ft) with an aspect ratio of 3.42 and NACA 0012-24 airfoil section. A schematic showing basic airplane dimensions is given in figure 1. Photographs showing the XV-5B in flight and installed in the wind tunnel are given in figures 2 and 3.

Instrumentation

Wind-tunnel test.- Wind-tunnel noise measurements were made using 1.27 cm (½-inch) condenser microphones (B&K 4133) with cathode follower (B&K 2615). The microphones and cathode followers were connected to signal conditioners, and the outputs from the signal conditioners were recorded on magnetic tape at 30 ips on an Ampex FR-1300A tape recorder. Before each run, each microphone was calibrated with a 250 Hz piston phone to 124 dB at .5 volt RMS. Overall system error is estimated at ±½ dB.

The microphones were at equal height on microphone stands along the wind-tunnel floor and had bullet nose cone wind screens (B&K UA 0052). With the nose cones installed the microphones had omni-directional response. The microphones were pointed into the wind during the wind-tunnel test. A schematic of the wind-tunnel microphone array is shown in figure 4.

Sound van.- Flyover noise data measurements were made using a portable sound data van. The self-contained van had all necessary equipment for data recording and on-site data reduction.

The sound data measurements were made with 1.27-cm (½-inch) condenser microphones (B&K 4134) with cathode followers (B&K 2619). Each microphone and cathode follower was connected to a portable signal conditioner at the mircrophone site, and the portable conditioner was connected by long cables to a van signal conditioner. The van-to-portable conditioner arrangement allowed both on-site and remote setting of signal gain. The signal output at the van was recorded on magnetic tape at 30 ips using a Honeywell tape recorder. In addition to microphone signals; time code, Fairchild camera signal, operator voice, and pilot voice were recorded.

Prior to the test series, the long microphone cables, signal conditioners and cathode followers were calibrated with a sine wave signal generator. The input to each system from the signal generator was 1 volt RMS at each 1/3-octave center frequency from 50 to 10,000 Hz. The output from each system was recorded on magnetic tape and was used for data correction.

Shortly before the day's flights, each microphone was calibrated with a 250 Hz piston phone to 124 dB and 1 volt RMS. Overall system error is estimated to be less than ± ½ dB.

The microphones were set on 1.83 m (6 ft) stands and adjusted to receive grazing incidence from the sound source. Each microphone had a wind screen made of polyurethane foam (B&K UA 0237). The microphone arrangement is shown in figure 5.

Wind velocity and direction, dry and wet bulb temperatures, barometric pressure, and humidity were measured during each flight at a portable weather station located near the van. Weather conditions were obtained prior to each day's flights. If the wind velocity exceeded 5 knots, the relative humidity exceeded 90% or was below 30%, or temperature exceeded 86°F or was below 41°F, the day's flights were cancelled.

Radar.- A portable radar was used to guide the aircraft along the flight path and to provide information on aircraft position with respect to the microphone field. The radar signal was received from a reflector attached to the nose wheel of the XV-5B. The radar output was aircraft range, altitude above the runway surface, and displacement from the runway centerline.

Fairchild flight analyzer camera.- A Fairchild Flight Analyzer Camera was used to determine when the aircraft was directly over the reference acoustic center of the microphone field. The camera took a series of photos on a single photo plate when swept across a viewing field. Careful set-up of the camera allowed accurate determination of aircraft altitude and flight speed. In order to synchronize the camera with the sound data recordings, a pulse signal was emitted from the camera at each shutter click, and was recorded at the sound van simultaneously with the acoustic data. The set-up distances from the runway for the camera are shown in figure 6. A sample photo plate is shown in figure 7.

TEST PROCEDURE

Wind Tunnel

Wind-tunnel noise data were taken with the aircraft operating at equivalent flyover conditions. Approximately 2 minutes of sound data were recorded at each point. Voice inputs for airplane configuration, wind-tunnel air velocity, airplane power setting, and microphone gain settings were recorded simultaneously with the sound data. Wind-tunnel relative humidity and temperature were measured before each run.

Flyover

The sound data recording equipment was turned on when the aircraft entered the approach path to the microphone field. The data recording continued until the aircraft lifted off at the end of the runway near the sound van. Data were recorded approximately 243.84 m (800 ft) on either side of the microphone field. Prior to the day's flights a background noise level was recorded for reference when reducing data.

DATA REDUCTION

Wind Tunnel Data

Data from wind-tunnel noise measurements were reduced with a B&K real time 1/3-octave-analyzer using an average 15-second data sample. The output from the analyzer was punched on paper tape for computer processing through a data reduction program.

The data reduction program calculated perceived noise levels (PNL) and applied corrections for wind-tunnel reverberations to the data (reference 3). The output from the program consisted of SPL for each 1/3-octave band, corrected and uncorrected overall SPL (total SPL for all bands) and corrected PNdB.

Flyover Noise Data

Data from the flyovers were reduced on site using the reduction equipment in the sound van. The data were reduced through a General Radio real-time 1/3-octave band analyzer using an averaging time of 1/8 second (due to speed of the aircraft). The output from the filter set was input to a mini-computer on board the van. The computer applied the electrical corrections from calibration and output a punched paper tape and printed sheet. The punched paper tape was used for further data reduction as reported in reference 2. The computer-printed listing consisted of PNL and PNLT for 80 data points 1/8 second apart. In addition, the 1/3-octave band SPL's were listed for each of the 80 points. An uncorrected EPNdB was listed for each set of data points. The data used for this report were the 1/3-octave SPL data produced on site from the van.

ANALYSIS

In order to compare the wind-tunnel data with the data from flyover, both sets of data were corrected to free field and atmospheric attenuation was added (reference 7). In addition, the flyover noise data were corrected for Doppler shift[6] and then extrapolated to wind-tunnel measurement distances, from source to microphones, by applying the spherical divergence law for sound attenuation (6 dB per double distance).

Corrections to wind-tunnel data were based on noise measurements of a dodecahedron sound source (12-sided polyhedron with a .203 m (8-inch) speaker in each surface) in the wind tunnel and in free field. The wind-tunnel calibration was done with the dodecahedron sound source suspended at the theoretical acoustic center of the XV-5B jet exhaust (approximately 5 tail-pipe diameters downstream from the exit). The XV-5B was not in the wind tunnel during this calibration. The microphone array was the same as that used during the XV-5B wind-tunnel test. The dodecahedron sound source was driven with pink noise through 1/3-octave bands with the input at each center frequency held constant at 12.5 volts RMS.

The free-field response of the dodecahedron was measured during early morning at the Ames V/STOL test pad site. The dodecahedron was suspended, using a crane, at 12.20 meters (40 ft) above a dirt field. A microphone was attached to a stand 10.67 meters (35 ft) high. The dodecahedron was driven with pink noise at the same power setting used in the wind tunnel and the response was recorded. At the selected height the error due to reflections was estimated to be less than ± 1 dB. The corrections applied to the wind-tunnel data were the differences at each 1/3-octave band between the tunnel calibration noise levels and the free-field noise levels as measured from the dodecahedron. The corrections account for reflection and reverberation in the wind tunnel.

The corrections to flyover data for reflections off a hard surface were based on references 4 and 5. To use the correction methods the following assumptions were made:

1) The aircraft was considered to be a point source with respect to each microphone.

2) The concrete surface of the runway was assumed to be a perfect reflector with no surface irregularities.

3) Spherical divergence was assumed for distance attenuation.

The corrections for reflections are sensitive to aircraft position with respect to a microphone. To minimize any error due to position a short data sample time of 1/8 second was selected. The short sample time, however, limits the number of data samples taken for any frequency. Data at lower frequencies is sampled fewer times than data at higher frequencies. Low-frequency spikes or nulls are more heavily weighted in a short time average. To minimize these errors, data which looked extreme were checked with data samples taken before and after; if the extreme point differed widely from the other samples, it was averaged.

Application of the Doppler equation at each microphone position used during the flyover test showed that the relative motion along a ray between source and microphone was high enough to cause any 1/3-octave center frequency to shift into an adjacent band. Data from microphones 1, 2, and 3 were shifted down one band since the relative motion of the source was toward the microphones. Data from microphones 4 through 10 were shifted up one band since the relative motion between the source and microphone was away from the microphones. Slight errors are introduced in shifting the data since it is difficult to account for energy associated with the shifted frequencies. However, on a broad-band spectrum the error is assumed small. The data were shifted after reflection corrections were made.

Background noise levels were plotted and compared to raw data to show source signal strength. Separations in level greater than 6 dB result in less than 1 dB error. If the signal strength is 14 dB or more above the background noise the error due to signal separation is 0 dB.

The errors due to corrections, data variability, and instrumentation for corrected data are estimated to be ± 3 dB for flyover data and ± 2.5 dB for wind tunnel data. Data repeatability for the wind tunnel data was ± 2 dB, no estimate can be made for flyover data. Tables 3 and 4 show the magnitude of correction applied to the data.

RESULTS

Uncorrected wind tunnel noise data are shown together with the corresponding background noise for 1/3-octave bands in figures 8

through 17. Uncorrected flyover noise data and background noise are similarly shown in figures 18 through 27. The wind tunnel source noise is 6 dB or more above background noise for all frequencies above 100 Hz. The flyover source noise is 10 dB or more at all frequencies below 6300 Hz.

The corrected data from flyover and wind-tunnel tests were plotted as SPL versus 1/3-octave band center frequency. Comparisons were made by plotting data from geometrically similar microphone positions for wind-tunnel and flyover tests on the same sheet. Overall SPL (OASPL) and PNdB for flyover data and wind tunnel data are tabulated for each position. The resulting spectrums are summarized in figures 28 through 37.

The spectrums show good agreement, on a 1/3-octave basis, between wind-tunnel noise data and flyover noise data. The differences in spectrum levels for the data plotted is 5 dB or less for most positions plotted. This difference is within the accuracy of the corrections applied to the data.

CONCLUSIONS

1) Flyover jet noise measurements can be duplicated in the wind tunnel when an appropriate calibration of the wind tunnel is made. Measurements made in the wind tunnel from model aircraft can be used to predict flyover jet noise for equivalent aircraft.

2) Wind-tunnel noise measurements have two advantages over data measured from flyover

    a) Wind tunnel data are not influenced by Doppler shifts, and

    b) Data sample times can be longer to give more averaging time to determine noise levels.

REFERENCES

1. Atencio, Adolph Jr.; and Soderman, Paul T.: Comparison of Wind Tunnel and Flyover Noise Measurements of the YOV-10A STOL Aircraft. NASA TM X-62,166, June 1972.

2. The General Electric Company: Inflight Sound Measurements on the XV-5B and OV-10 Aircraft. NASA Contract NAS 2-5462, April 1972.

3. Bies, David A.: Investigation of the Feasibility of Making Model Acoustic Measurements in the NASA Ames 40- by 80-Foot Wind Tunnel. CR 114352, Bolt, Beranek, and Newman Inc., 1971.

4. Hoch, R.: Acoustics Effects Produced by a Reflecting Plane. SAE No. 31, September 1970.

5. Howes, Walton L.: Ground Reflection of Jet Noise. NASA Technical Report, R-35, 1959.

6. Morse, Phillip M.; and Ingrad, K. Uno: Theoretical Acoustics, 1968.

7. Anon: Standard Values of Atmospheric Absorption as a Function of Temperature and Humidity for Use in Evaluating Aircraft Flyover Noise. Society of Automotive Engineers Inc., August 31, 1964.

TABLE 1

Configuration Details, Altitude and Airspeed Comparisons

	FLYOVER	WIND TUNNEL
Altitude ~ m (ft)	13.4 (44)	4.88 (16)
Airspeed ~ Knots	101	101
Power setting ~ $\frac{N}{\sqrt{\theta}}$ ~ (% RPM)	84.5 @ 47°F	83.5 @ 100°F
Aircraft pitch ~ deg	10.7°	10.7°
Gross Weight ~ Kg (lb)	4807 (10,600)	NOT APPLICABLE

TABLE 2

Sound Source To Microphone Distance And Acoustic Angle

	FLYOVER		WIND TUNNEL	
MICROPHONE	SOUND SOURCE TO MICROPHONE DISTANCE METERS (FEET)	ACOUSTIC ANGLE deg	SOUND SOURCE TO MICROPHONE DISTANCE METERS (FEET)	ACOUSTIC ANGLE deg
1	52.95 (173.70)	12.3°	16.48 (54.10)	11°
2	34.41 (112.92)	18.5°	10.34 (33.90)	16.5°
3	26.83 (88.02)	23.0°	7.76 (25.48)	21.4°
4	26.83 (88.02)	23.0°	7.76 (25.48)	21.4°
5	37.12 (121.79)	17.3°	11.34 (37.22)	15.1°
6	45.66 (149.80)	14.2°	14.25 (46.78)	12.1°
7	52.95 (173.70)	12.3°	16.48 (54.10)	11.0°
8	60.22 (197.58)	10.9°	19.04 (62.47)	9.1°
9	78.04 (256.05)	8.4°	24.59 (80.67)	7.1°
10	80.97 (265.64)	8.1°	25.77 (84.55)	6.8°

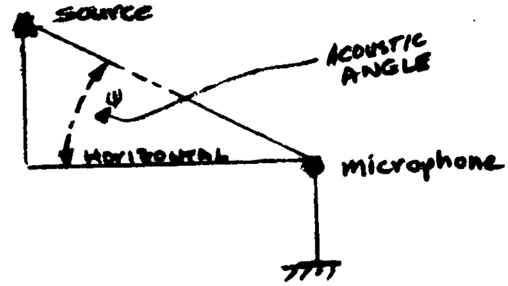

TABLE 3

Typical Corrections Applied To Flyover Data

Microphone 1

Frequency Hz	Raw Data SPL - dB	Reflection Correction dB	Distance Correction dB	Atmospheric Attenuation dB	Corrected Data * SPL - dB
50	75.3	-5.1	+10.1	0	80.3
63	81.3	-4.6			86.8
80	83.0	-3.8			89.3
100	79.3	-2.4			87.0
125	83.0	+.3			93.4
160	77.5	+6.8			94.4
200	** 82.8	+8.7			101.6
250	87.5	-.8			96.8
315	91.3	-4.9			96.5
400	92.5	-5.3			97.3
500	85.9	+.8			96.8
630	91.9	-2.2			99.8
800	89.6	-3.9			96.0
1000	91.8	-2.8			99.1
1250	90.3	+1.7		.5	99.2
1600	89.6	-3.0		.5	97.2
2000	89.9	-3.6		.7	97.1
2500	89.0	-2.3		1.3	98.1
3150	89.1	-2.9		1.5	98.5
4000	88.2	-3.3		2.2	97.2
5000	87.7	-2.9		2.6	97.5
6300	87.4	-2.9		3.6	98.2
8000	83.4	-2.9		3.6	94.2
10000	83.9	-2.9	+10.1	3.6	94.7

* No Doppler Shift correction

** Averaged point

TABLE 4

Typical Corrections Applied To Wind Tunnel Data

Microphone 1

Frequency Hz	Raw Data SPL - dB	Reverberation Correction dB	Atmospheric Attenuation dB	Corrected Data dB
50	98.0	-9	0	89.0
63	97.8	-9		88.8
80	103.0	-9		94.0
100	105.8	-8		97.8
125	104.8	-11		93.8
160	106.8	-10		96.8
200	109.0	-12		97.0
250	107.8	-10		97.8
315	107.4	-11		96.4
400	109.2	-11		98.2
500	109.0	-12		97.0
630	108.4	-11		97.4
800	107.4	-9		98.4
1000	108.0	-10		98.0
1250	108.0	-12		96.0
1600	107.4	-15		92.4
2000	107.0	-13	+.3	94.3
2500	106.0	-10	+.3	96.3
3150	106.8	-11	+.4	96.2
4000	104.8	-10	+.5	95.3
5000	103.4	-14	+.6	90.0
6300	101.8	-9	+.7	93.5
8000	107.4	-8	+1.0	100.4
10000	99.4	-7	+1.0	93.4

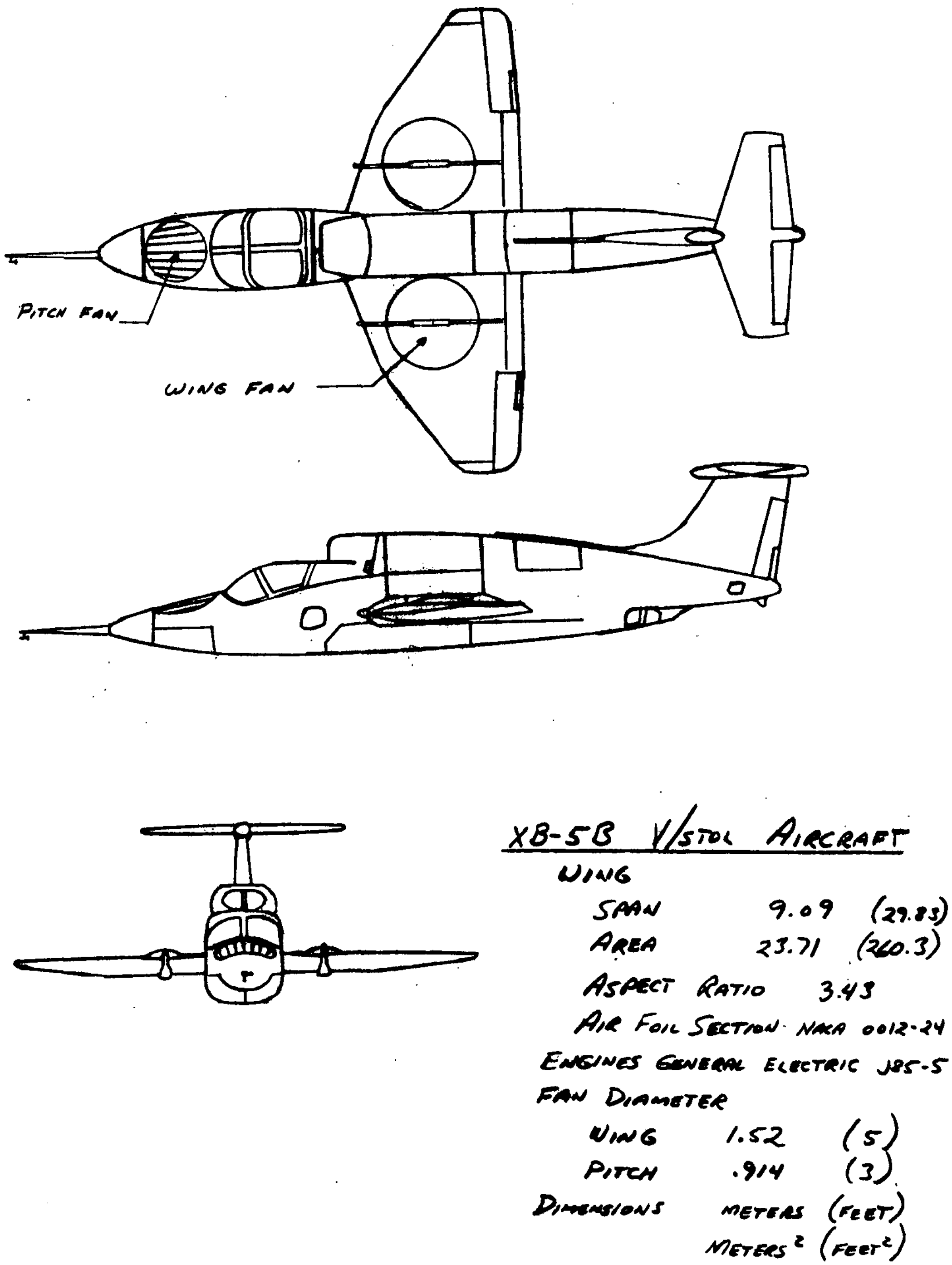

Figure 1.- Basic Airplane Geometry.

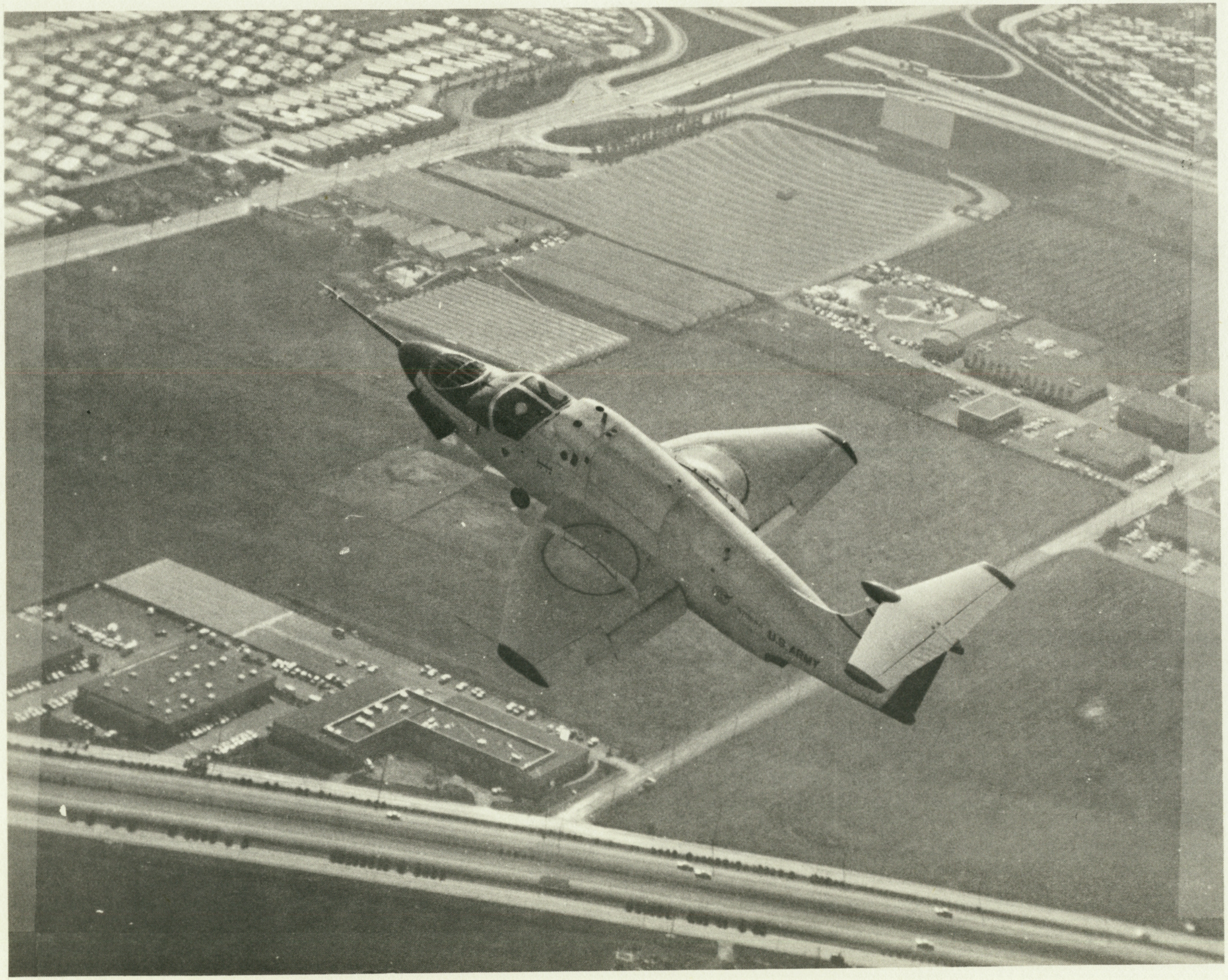

Figure 2. - XV-5B in Flight.

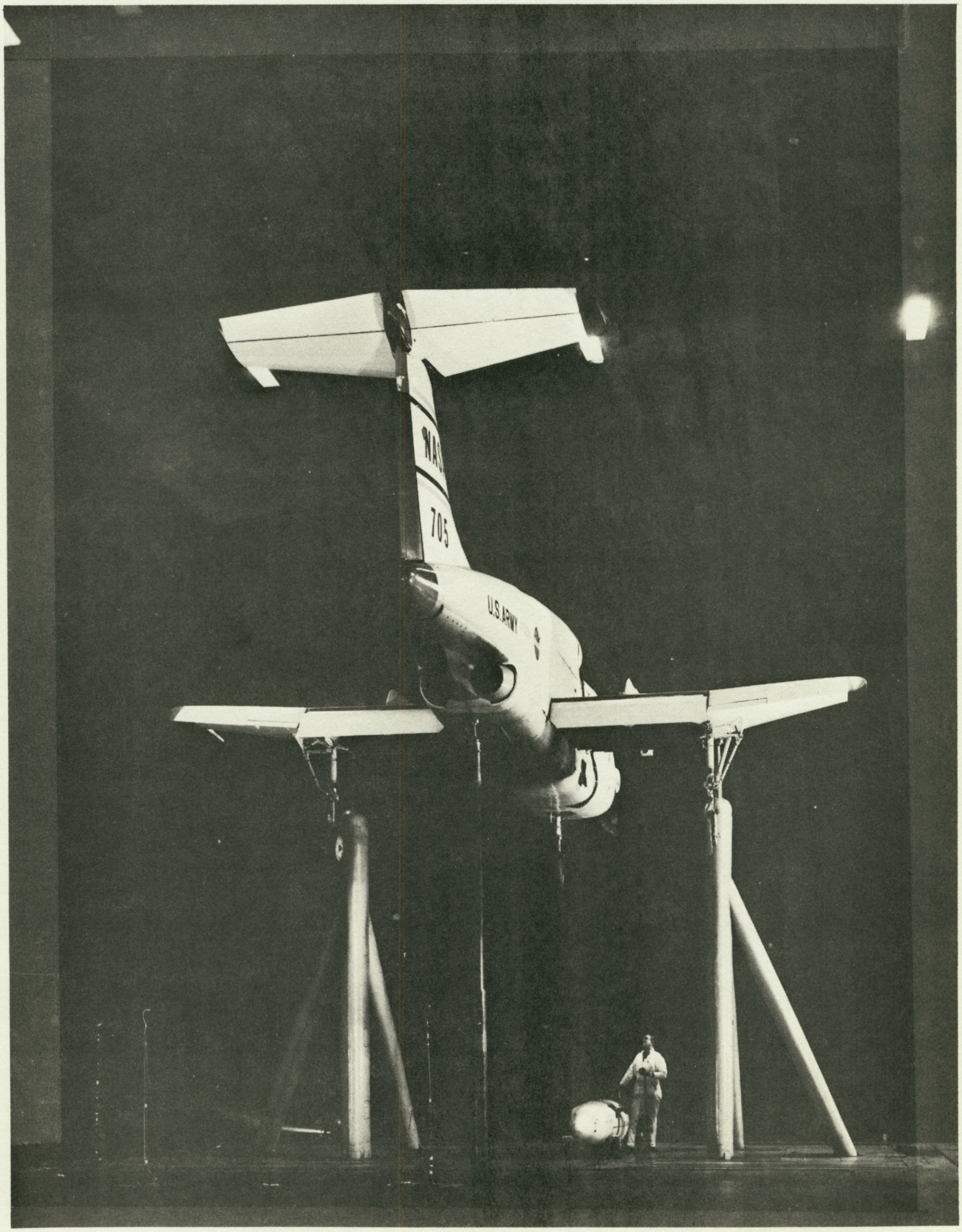

Figure 3. - XV-5B Installed in 40- by 80-Foot Wind Tunnel.

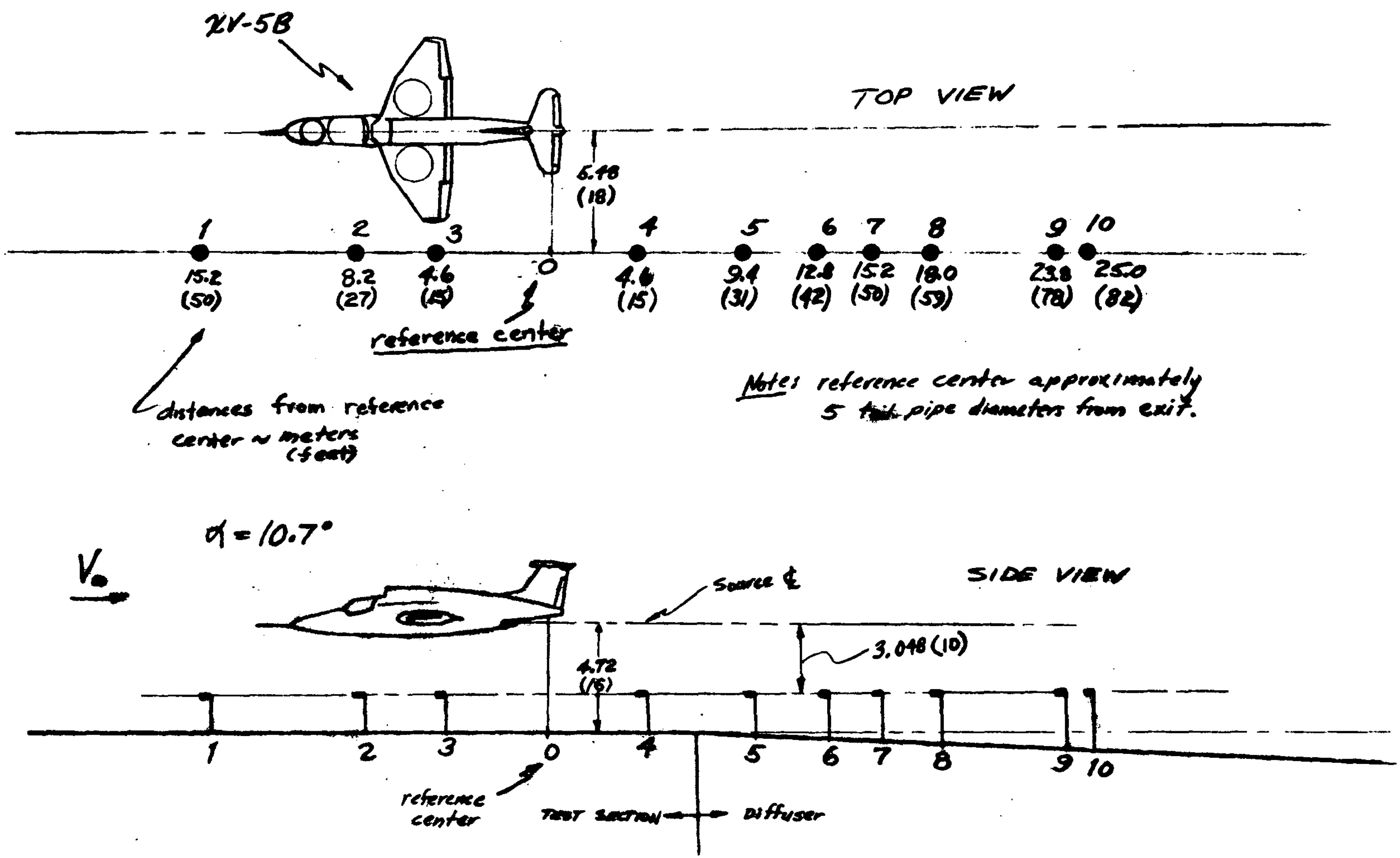

Figure 4. - Microphone Arrangement in 40- by 80-Foot Wind Tunnel.

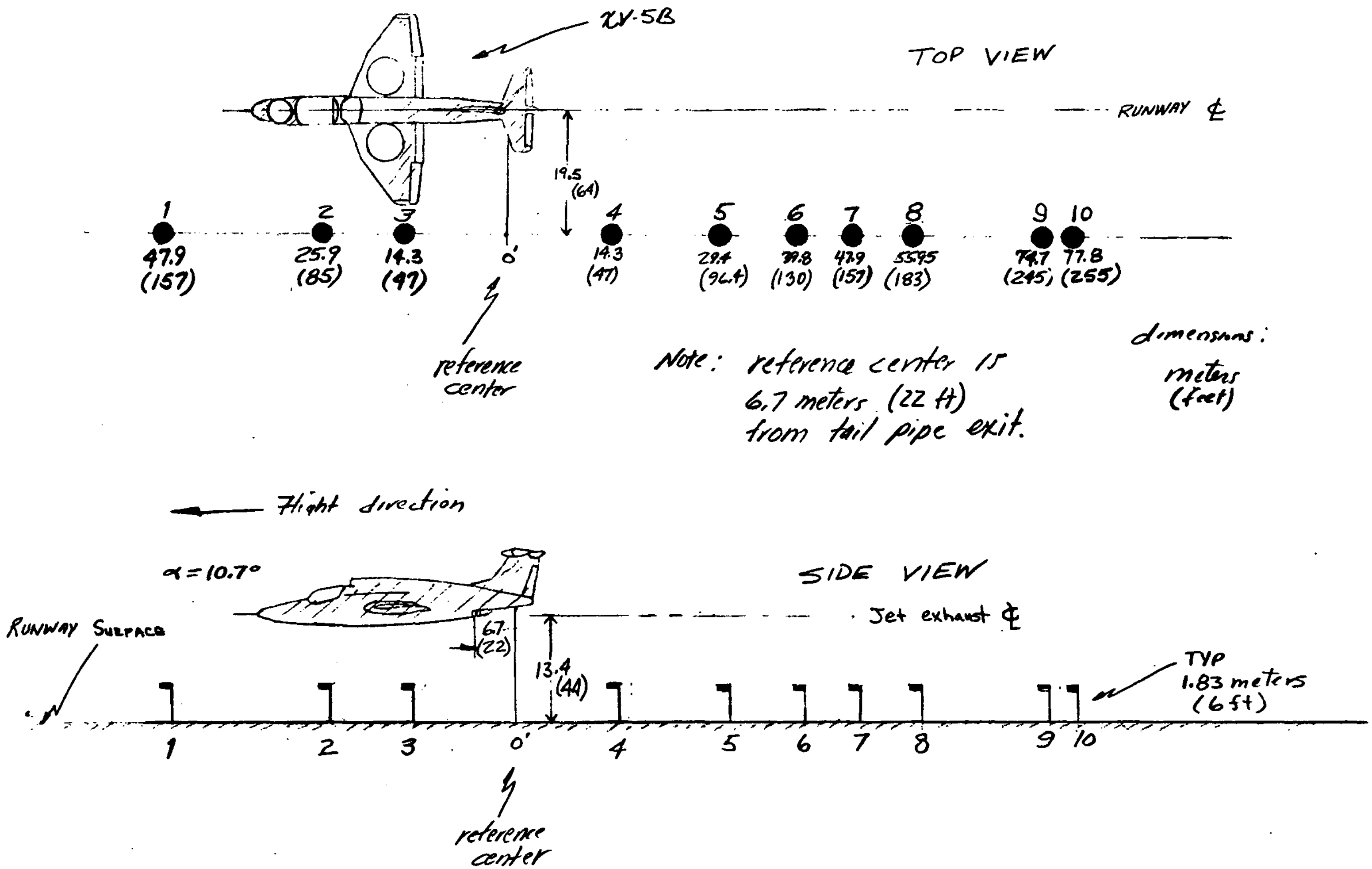

Figure 5. - Microphone Arrangement on Moffett Field Runway 32L.

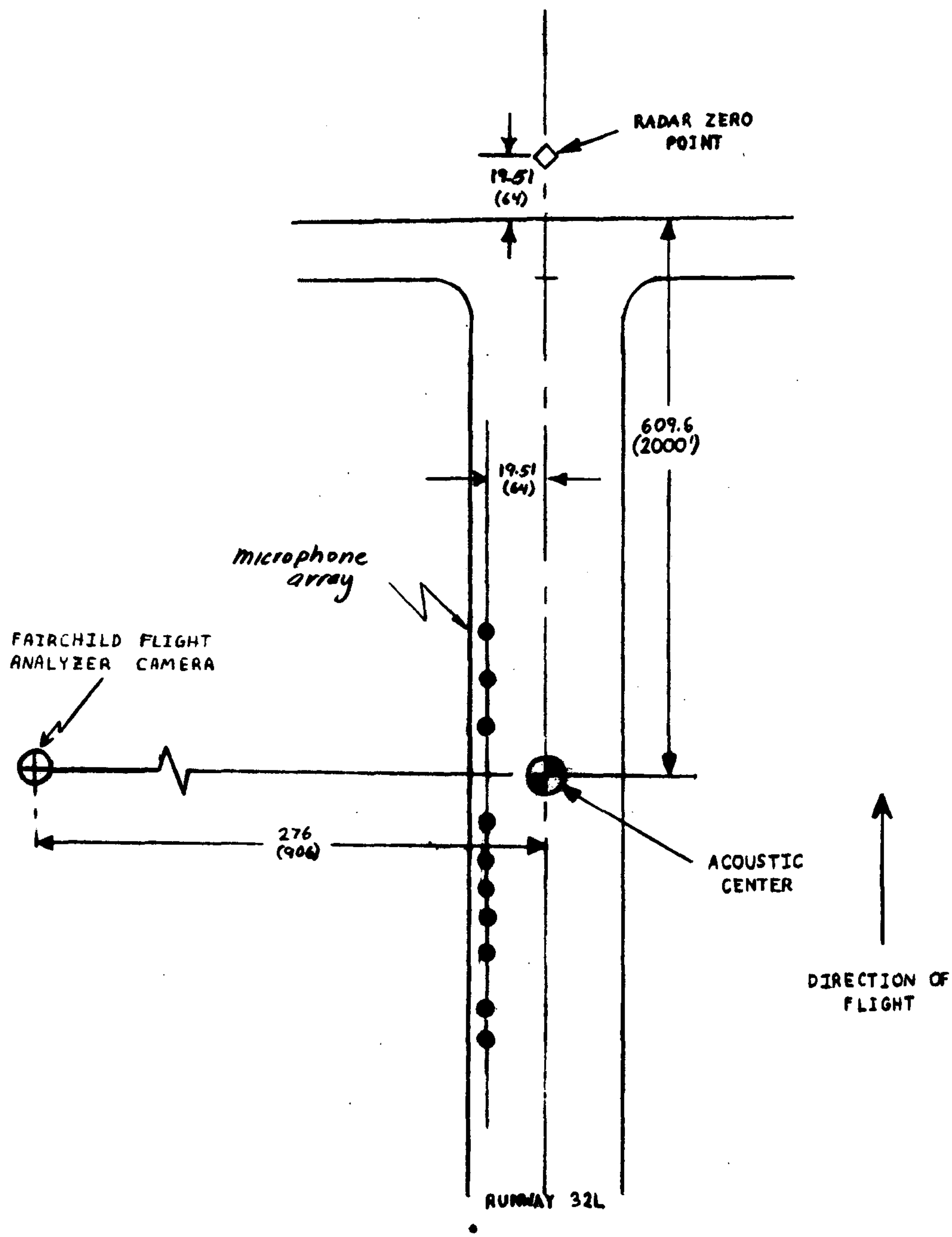

Figure 6.- Set up Distance for Fairchild Flight Analyzer Camera.

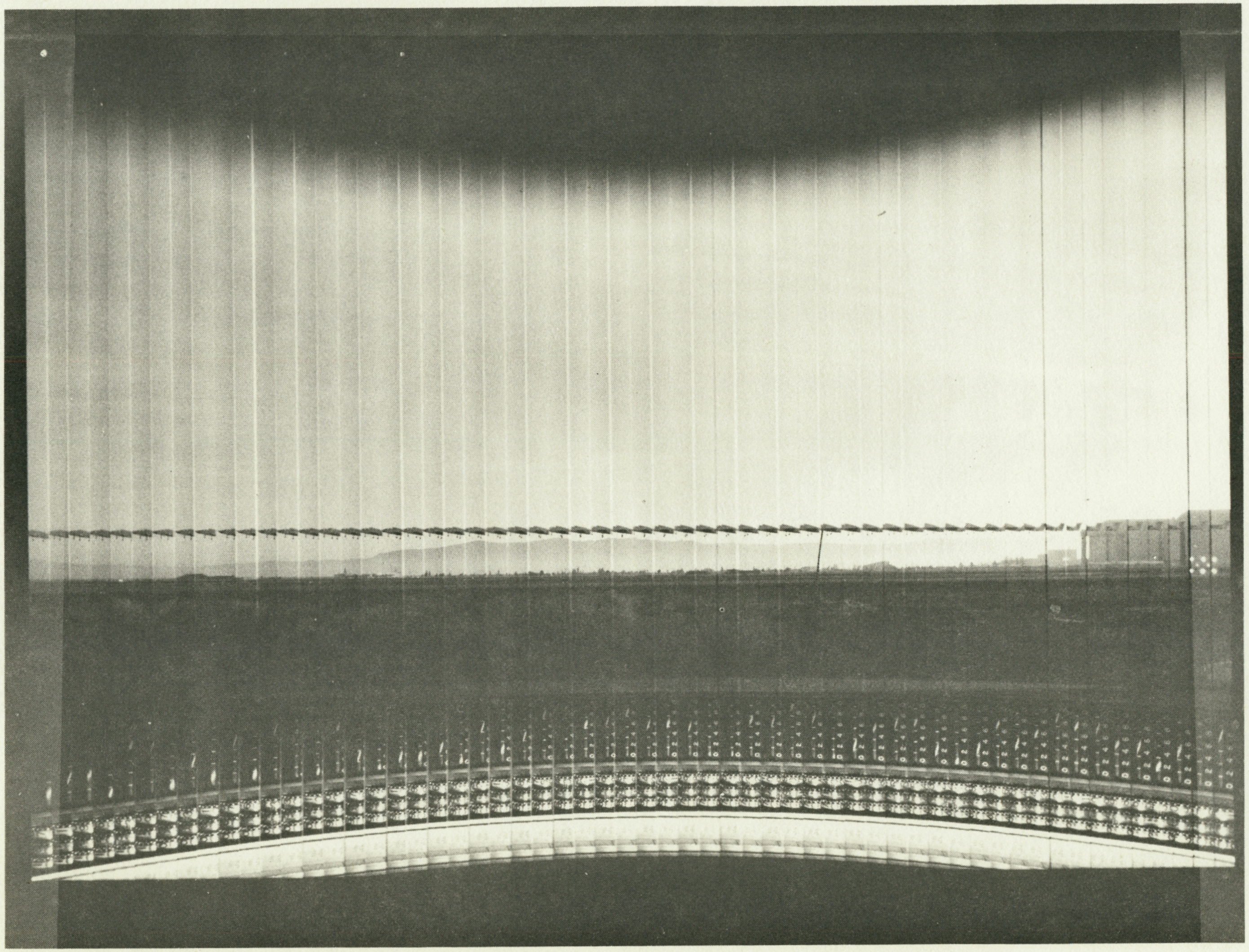

Figure 7. - Fairchild Flight Analyzer Photo Plate.

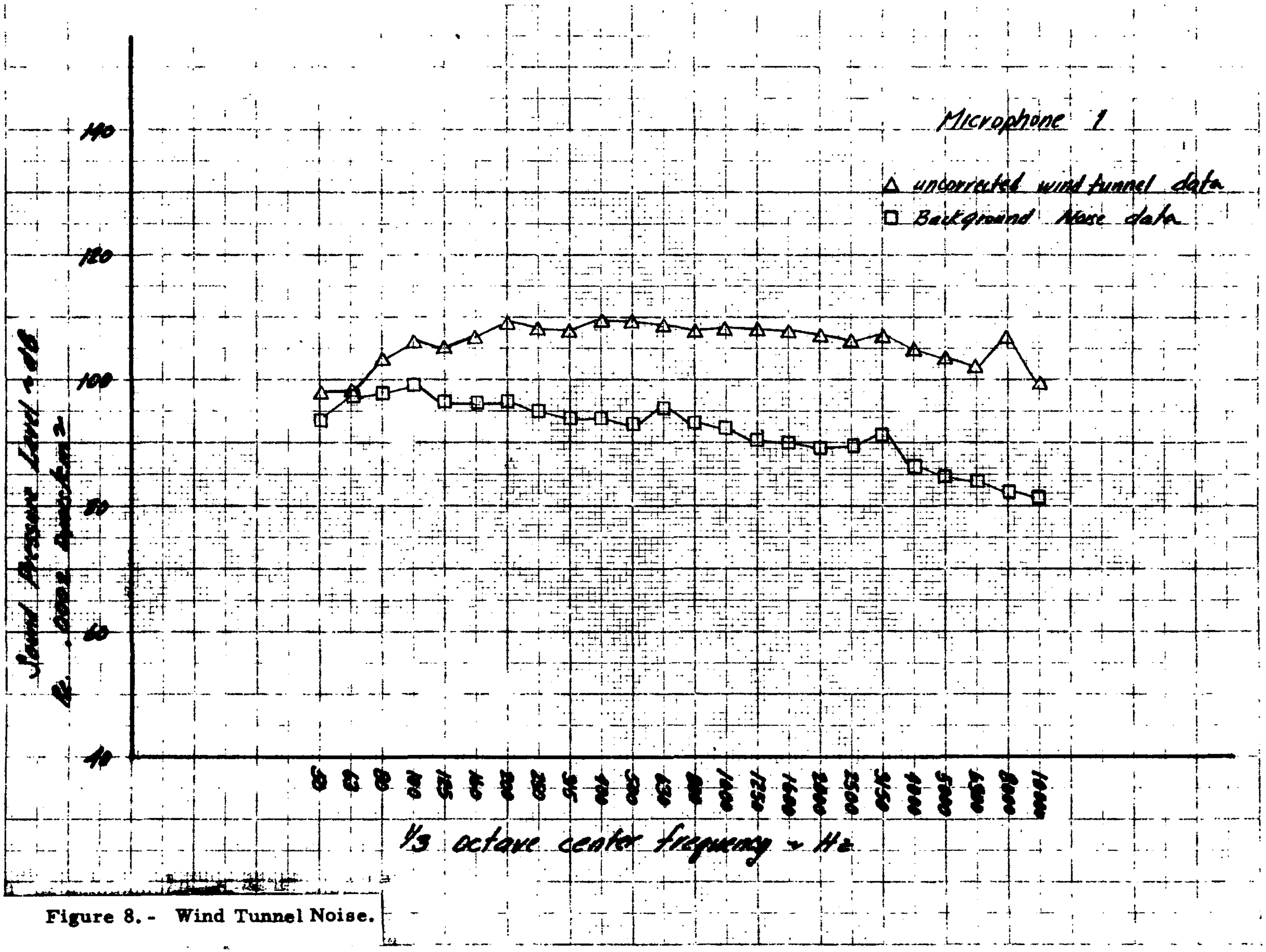

Figure 8. - Wind Tunnel Noise.

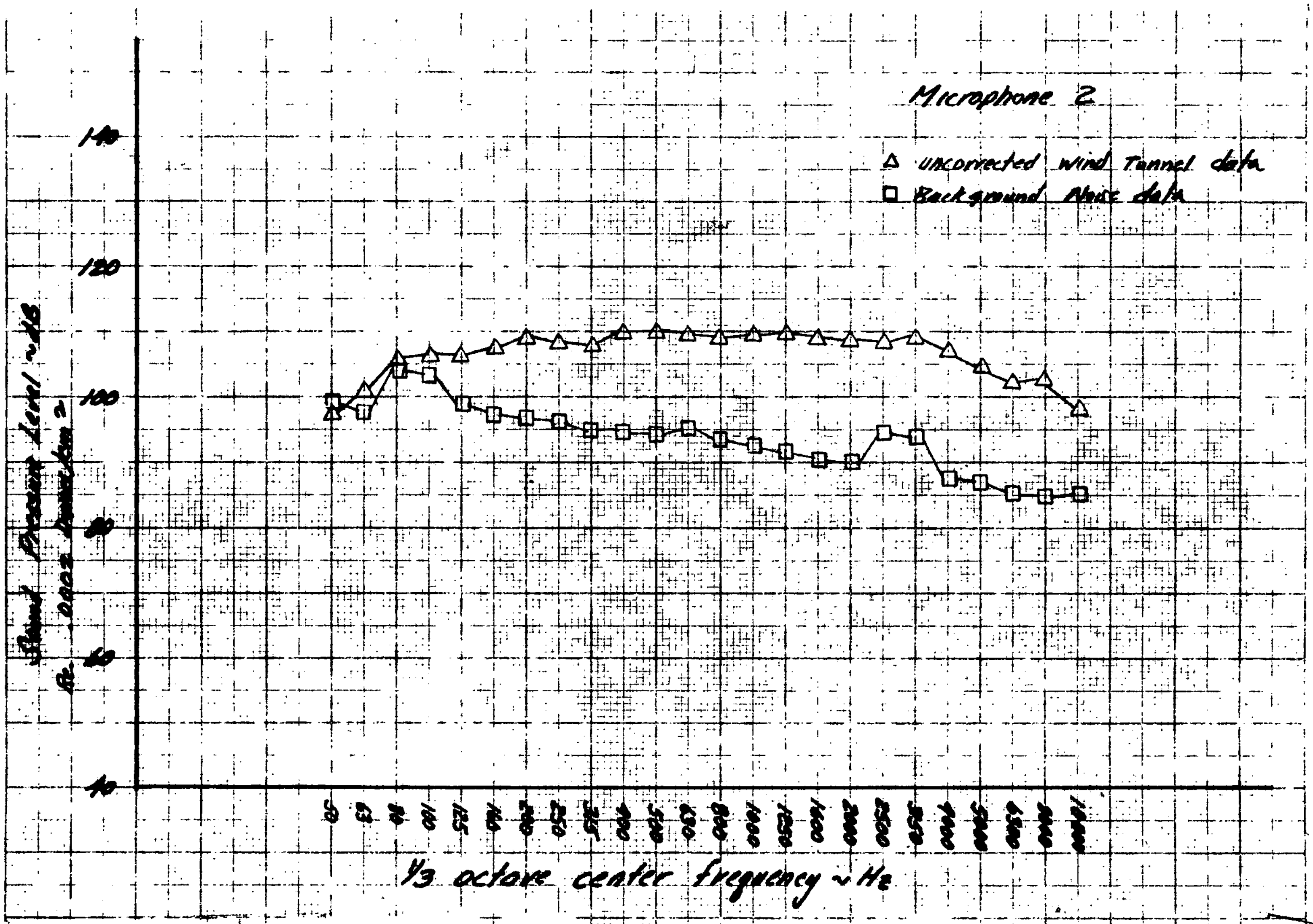

Figure 9.- Wind Tunnel Noise.

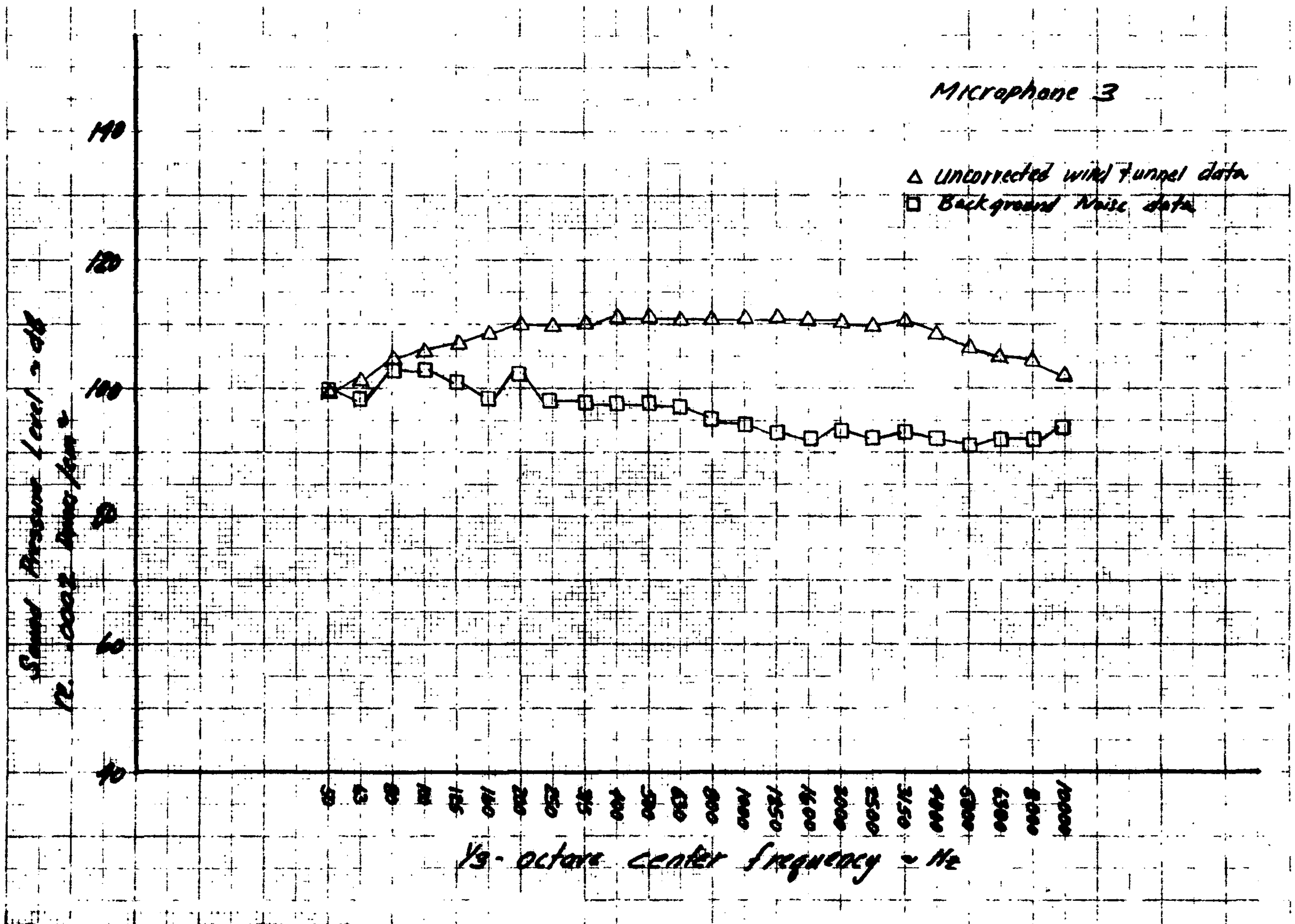

Figure 10. - Wind Tunnel Noise.

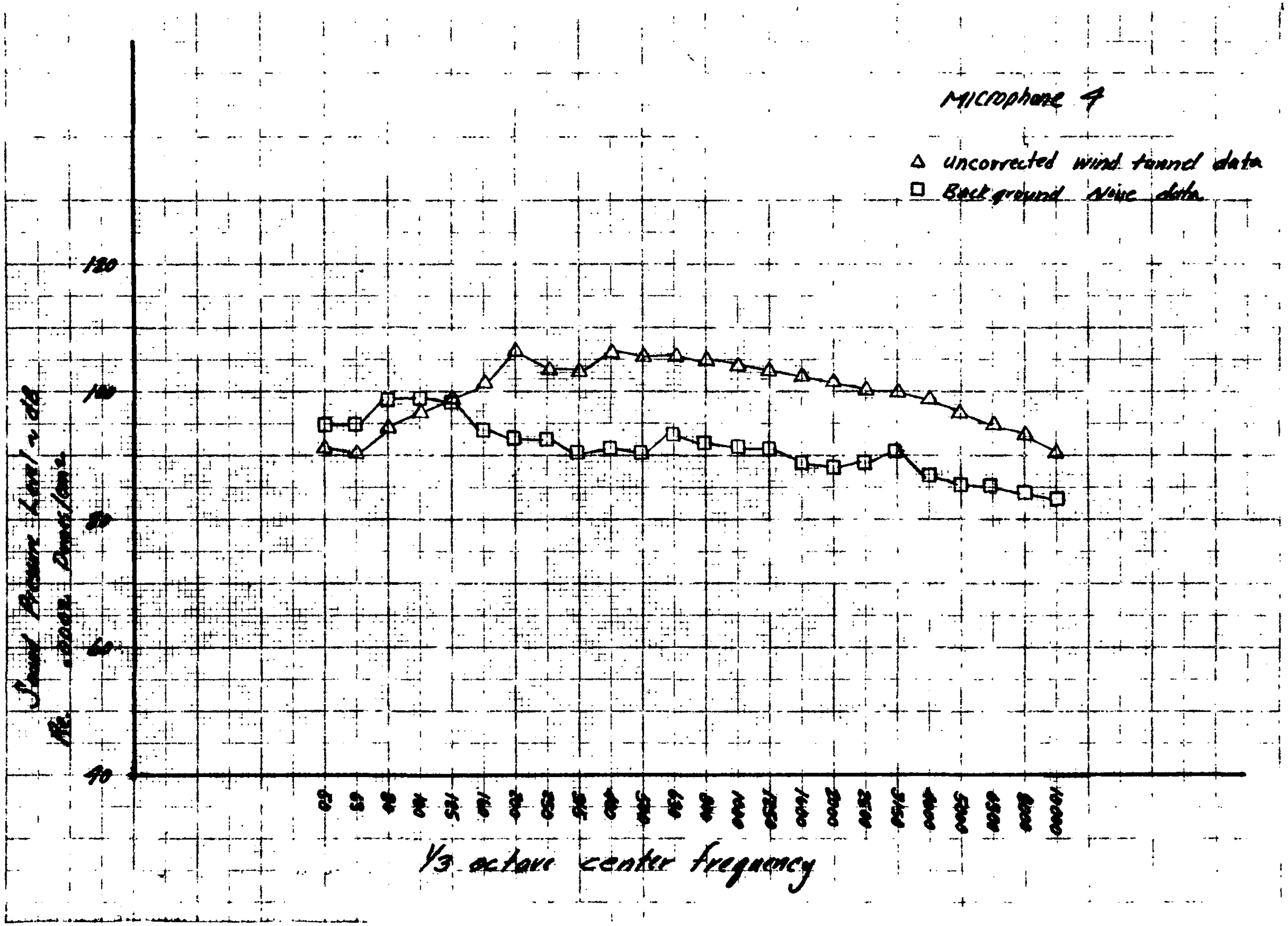

Figure 11.- Wind Tunnel Noise.

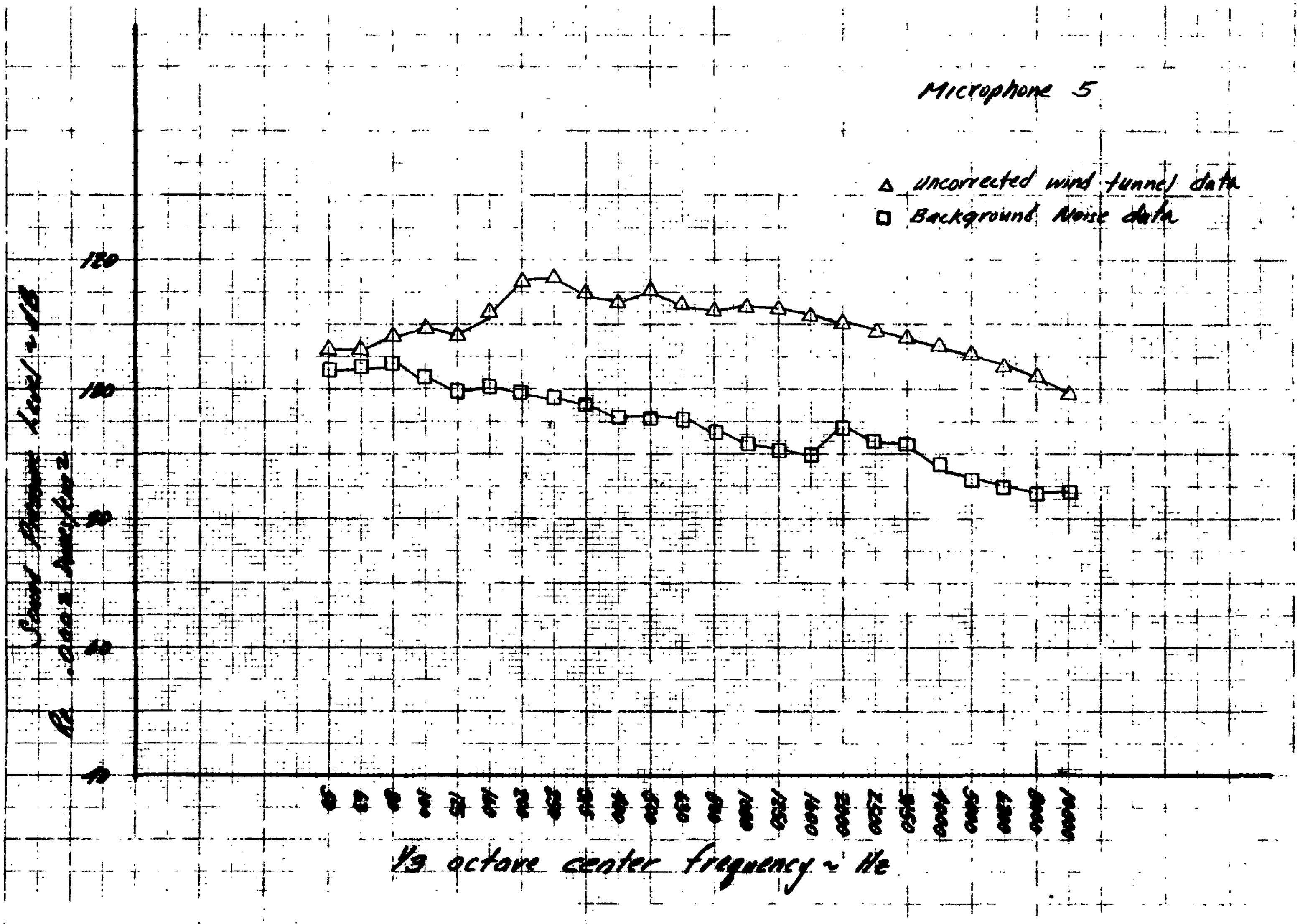

Figure 12.- Wind Tunnel Noise.

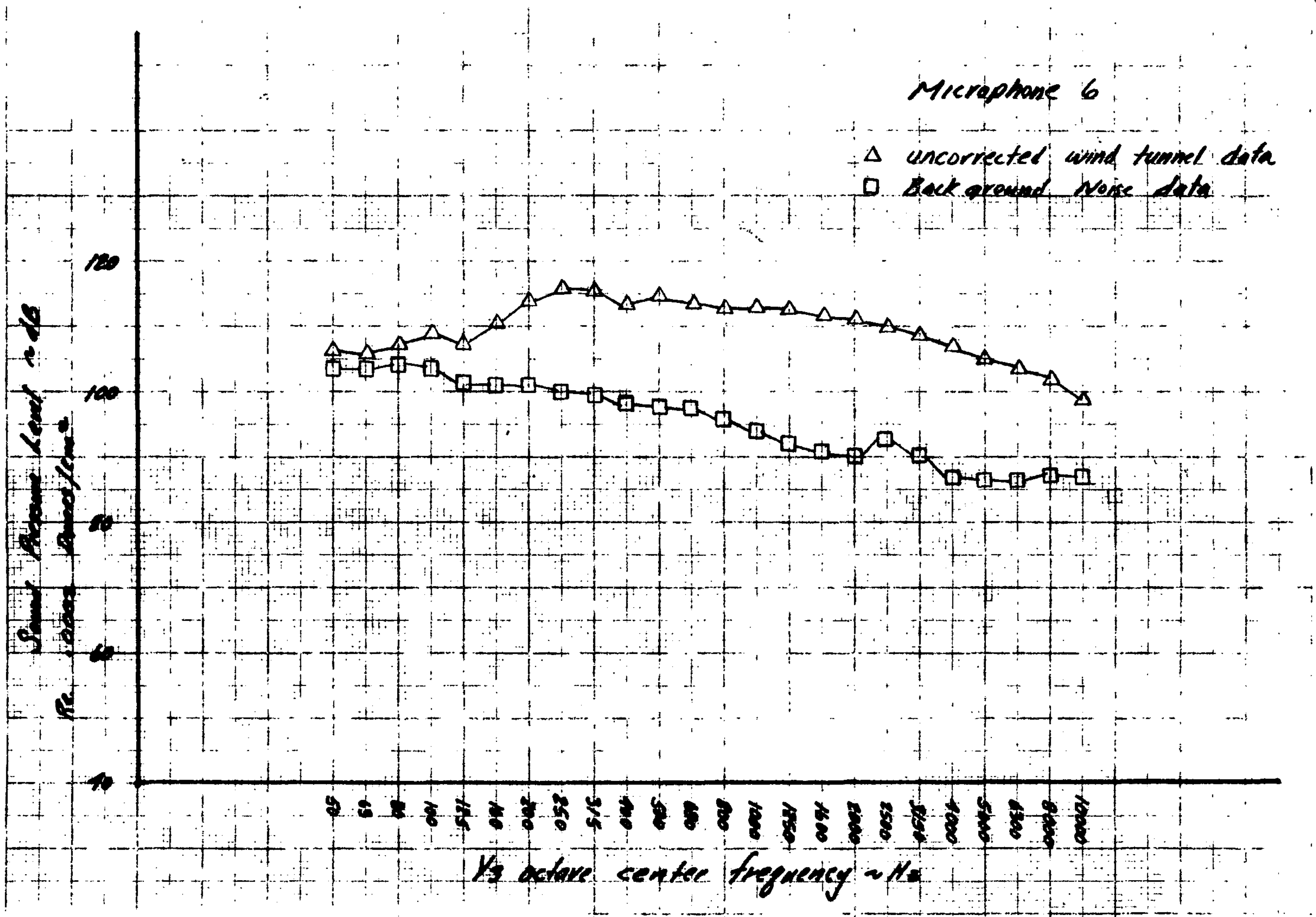

Figure 13.- Wind Tunnel Noise.

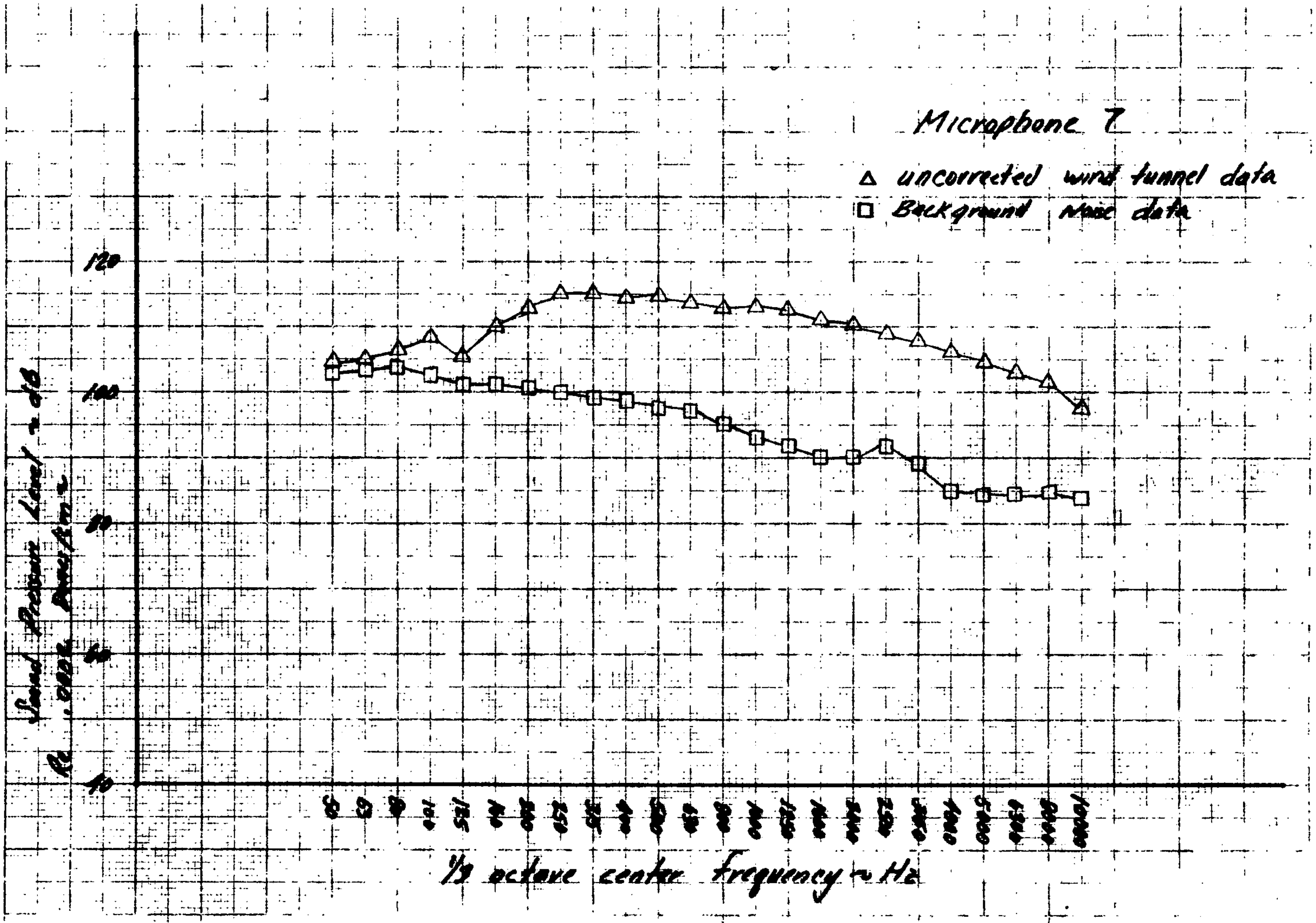

Figure 14. - Wind Tunnel Noise.

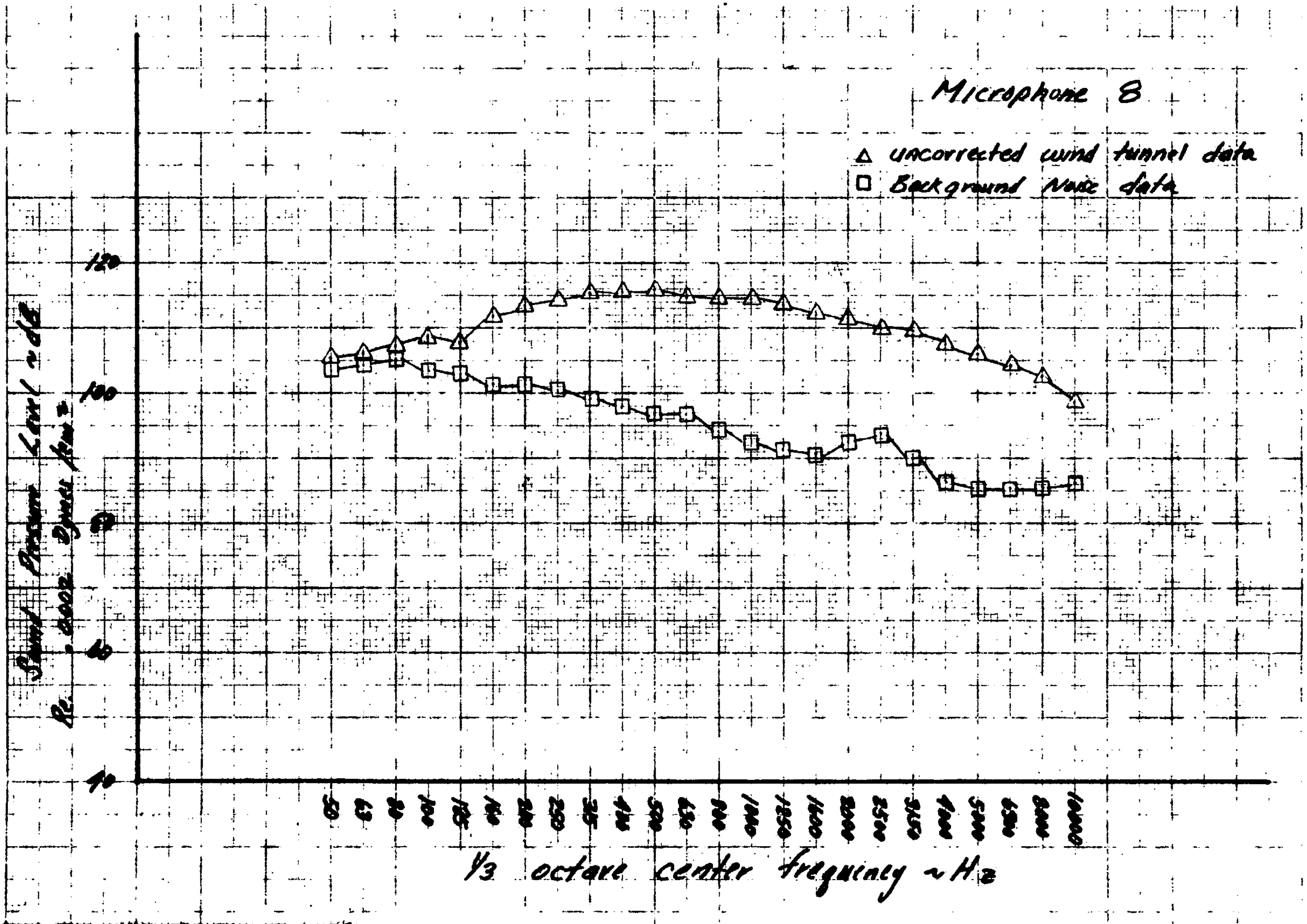

Figure 15. - Wind Tunnel Noise.

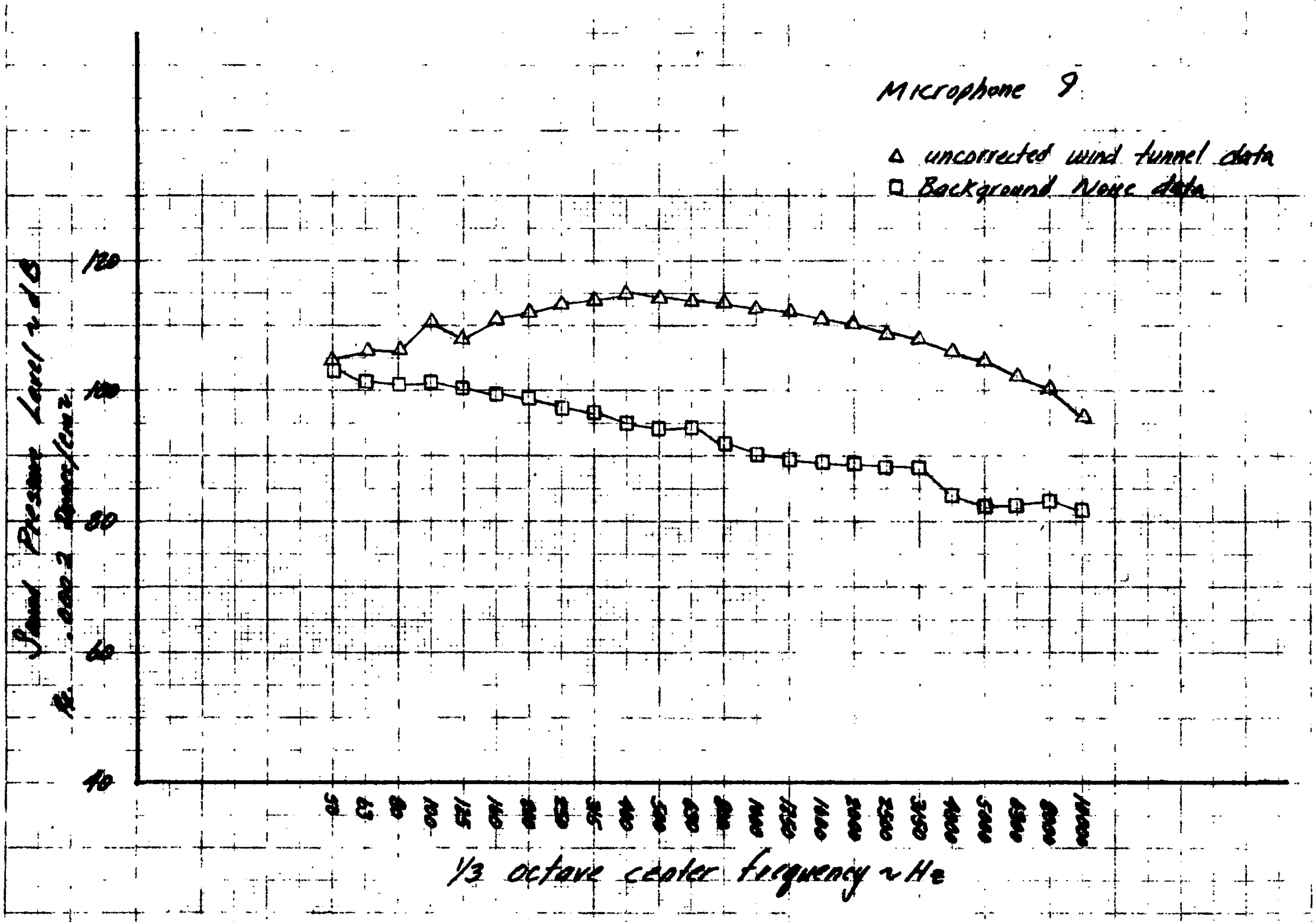

Figure 16.- Wind Tunnel Noise.

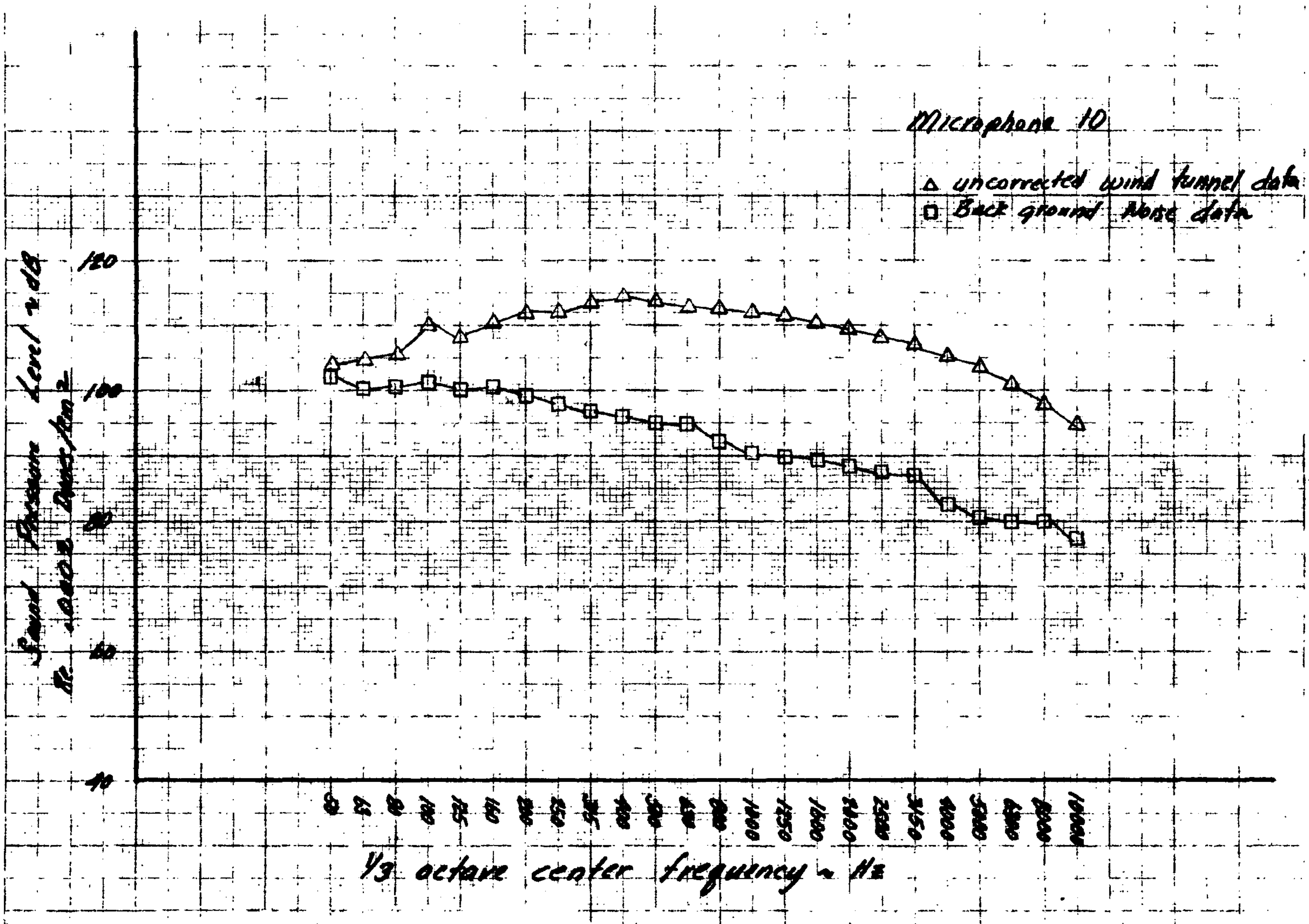

Figure 17. - Wind Tunnel Noise.

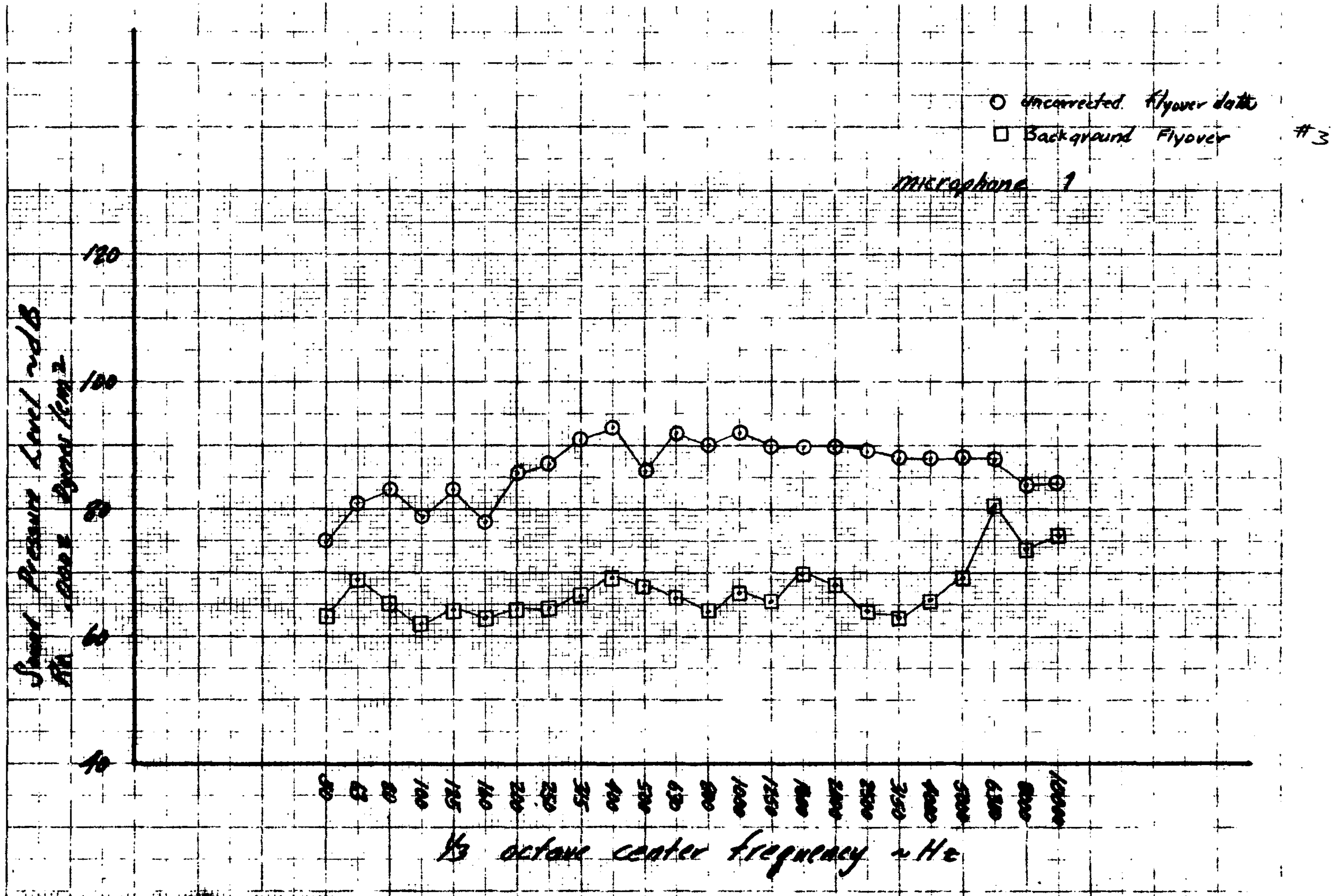

Figure 18.- Flyover Noise.

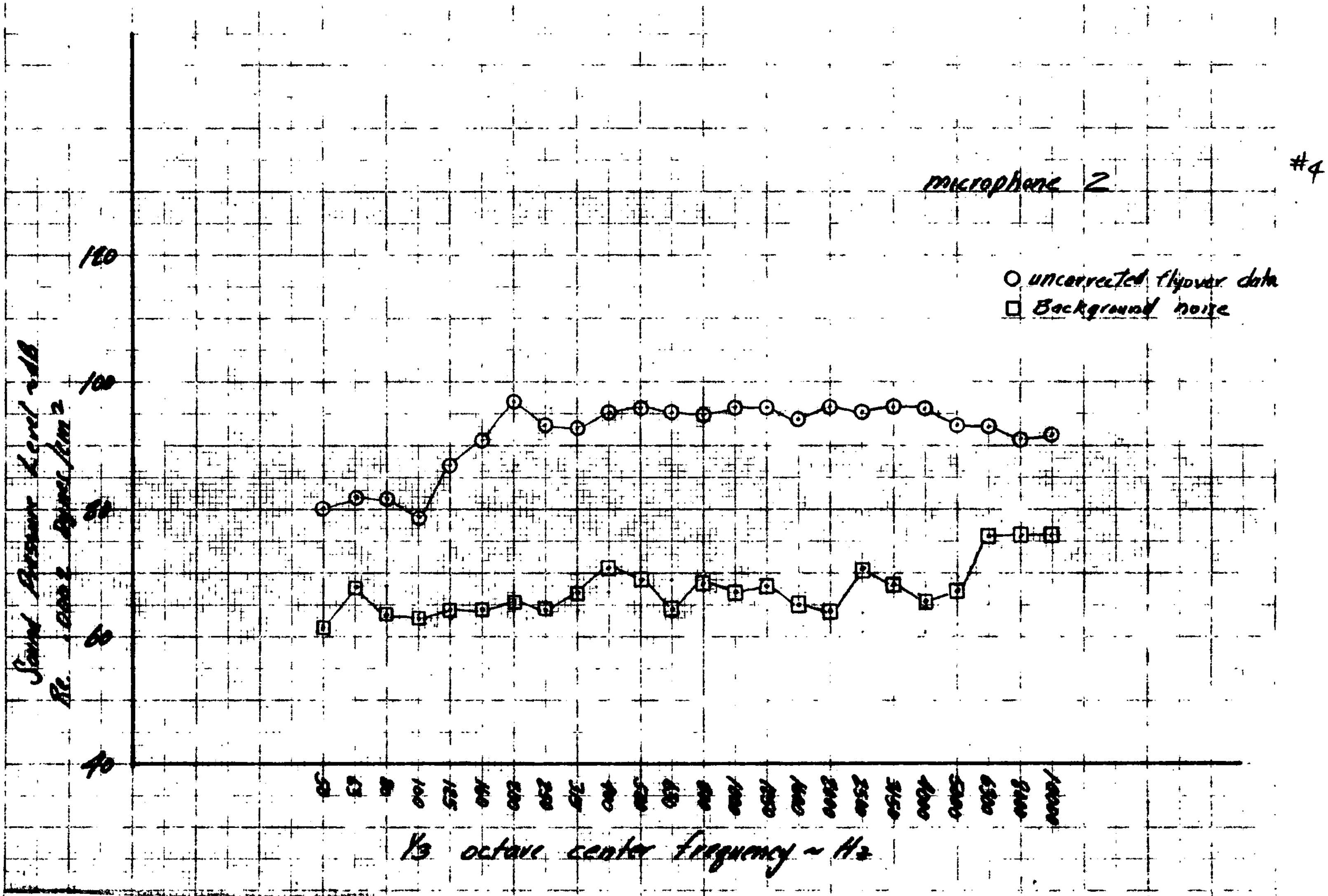

Figure 19.- Flyover Noise.

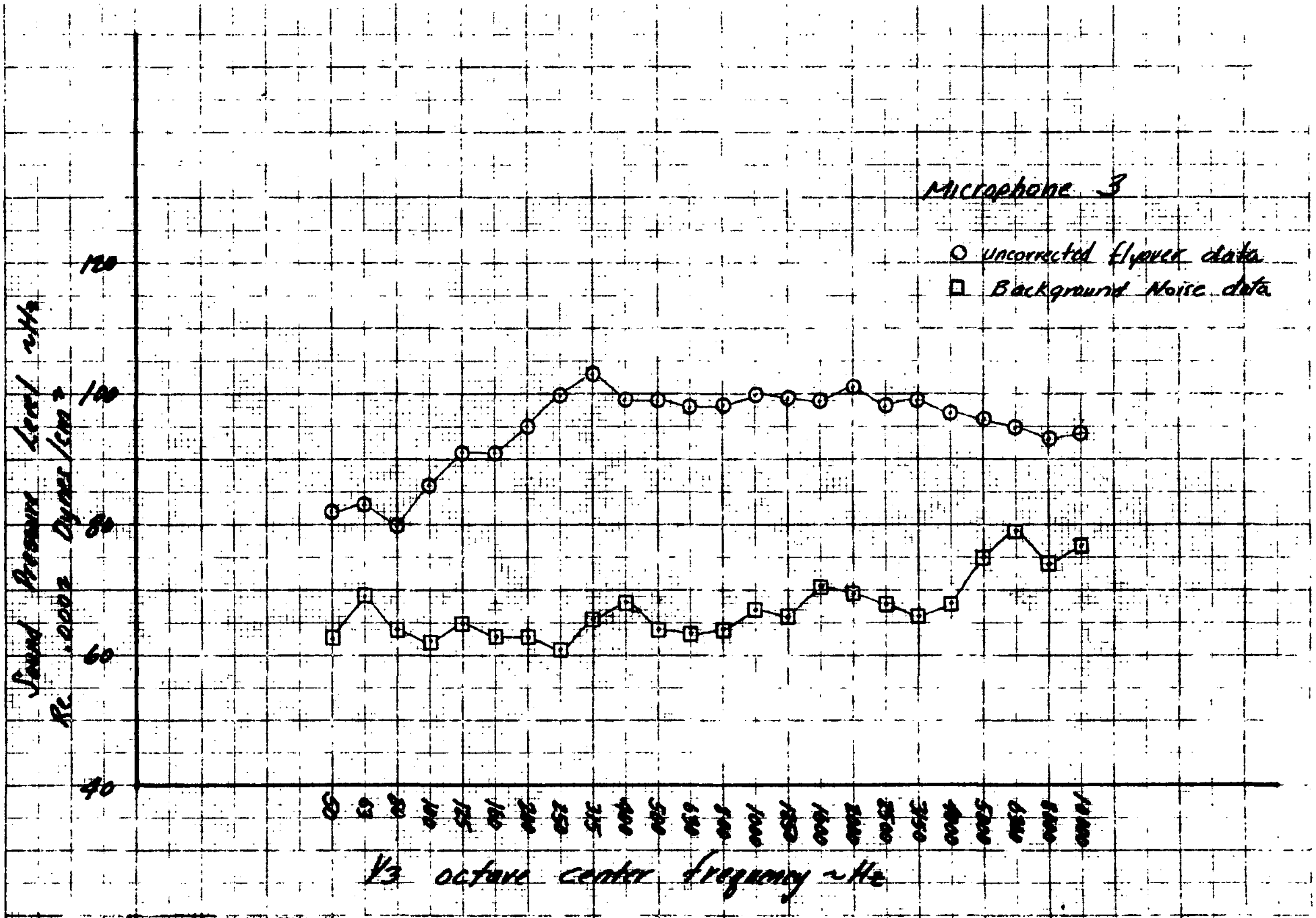

Figure 20.- Flyover Noise.

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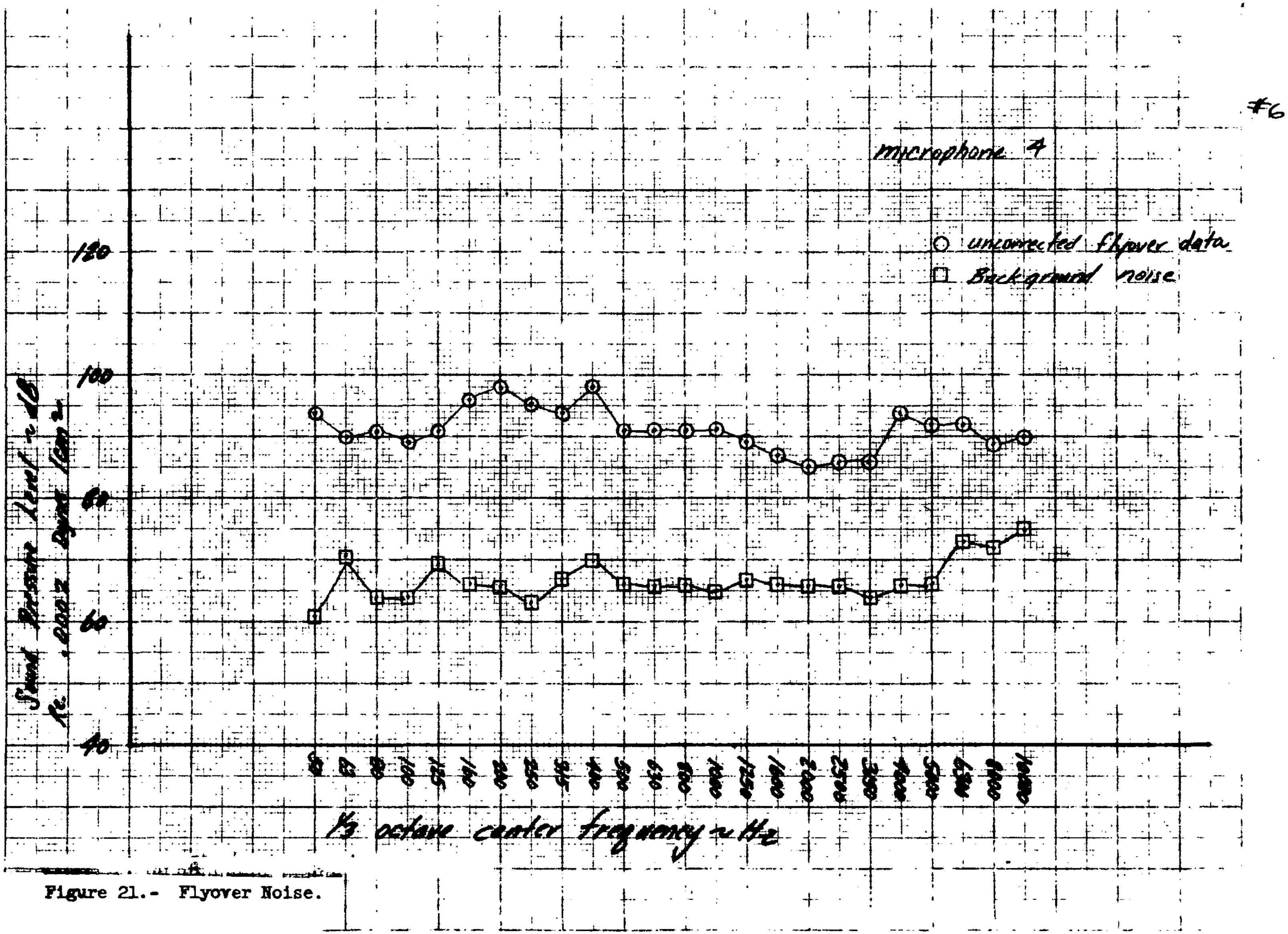


Figure 21.- Flyover Noise.

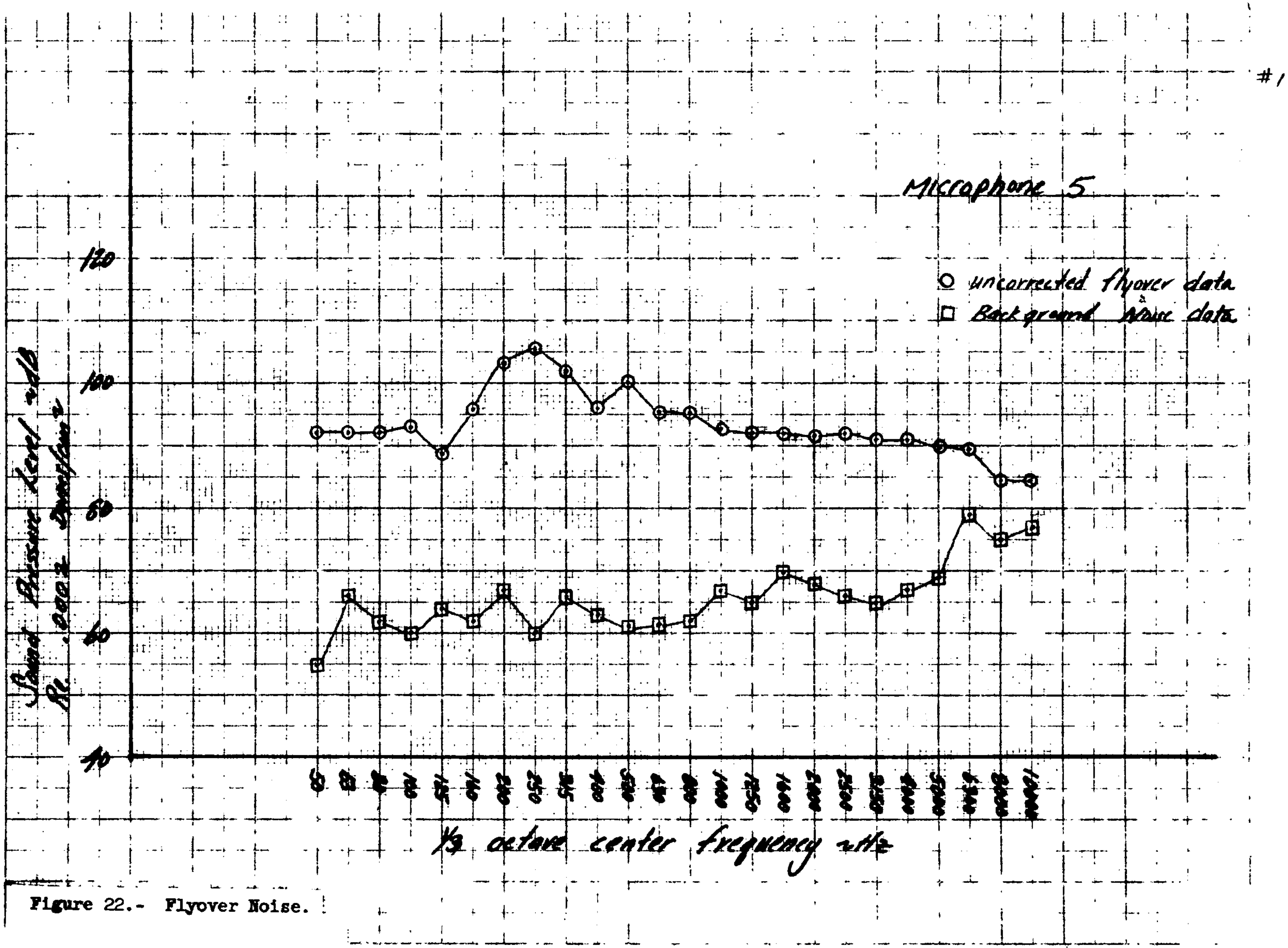


Figure 22.- Flyover Noise.

#2

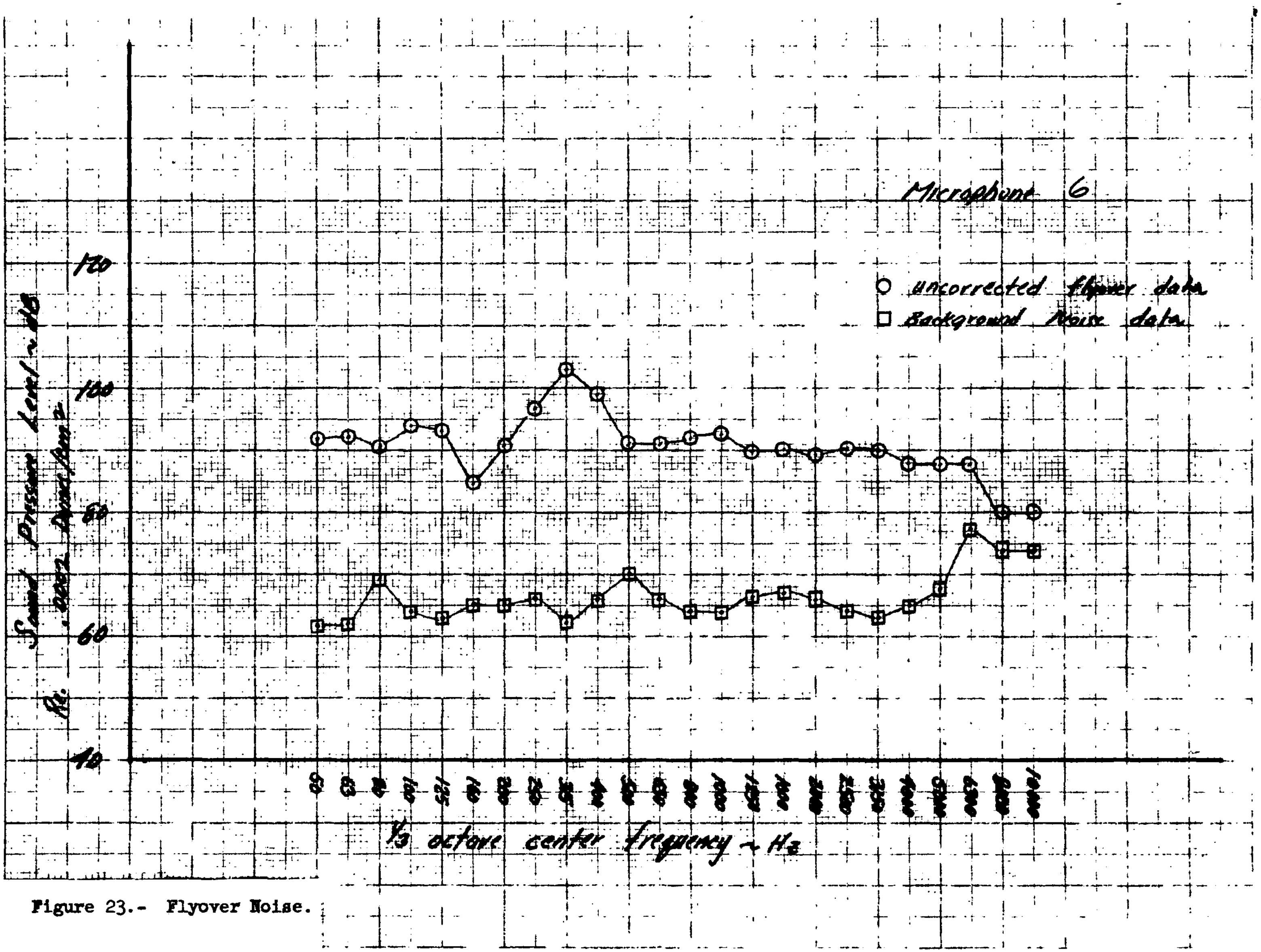


Figure 23.- Flyover Noise.

#7

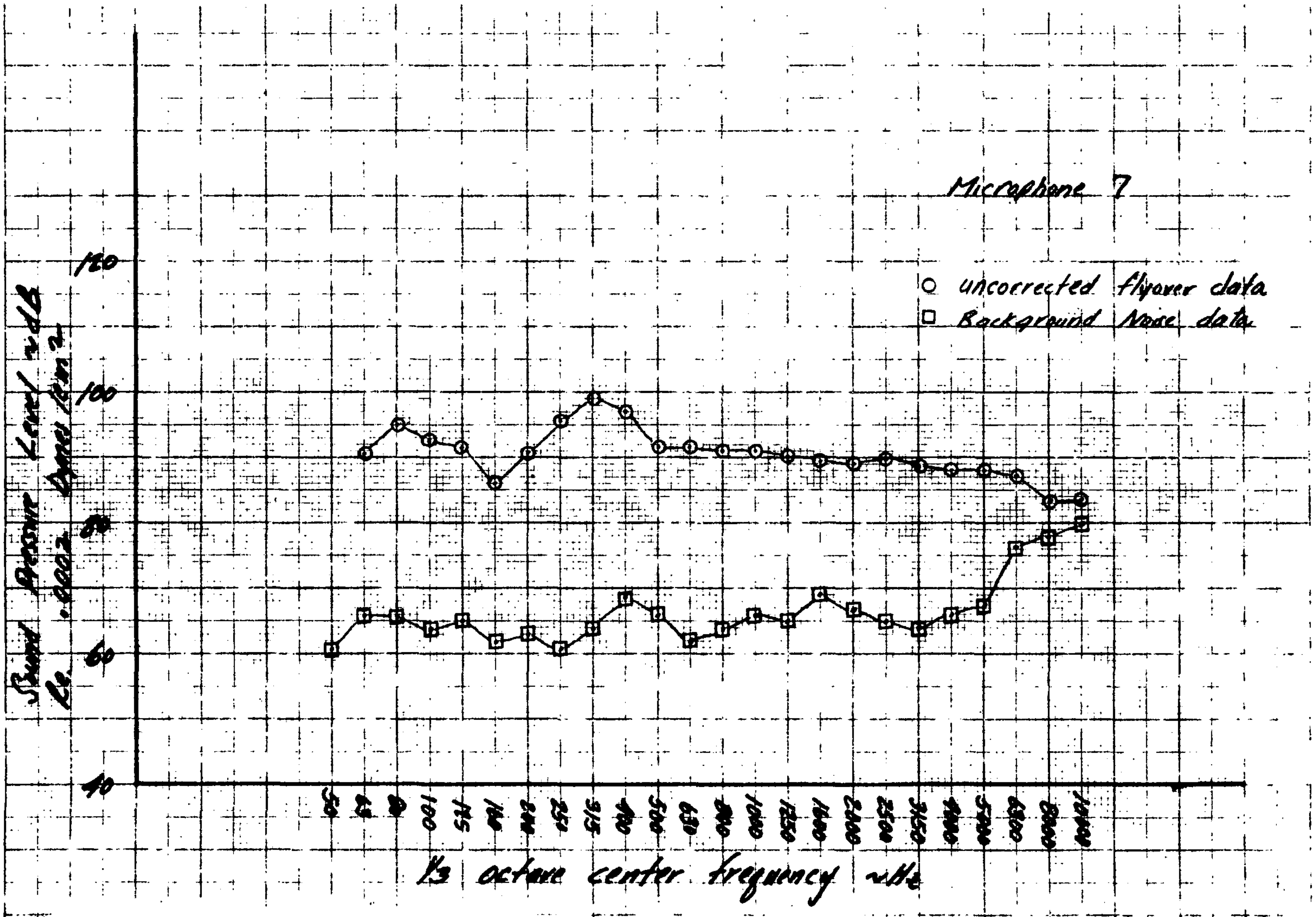


Figure 24.- Flyover Noise.

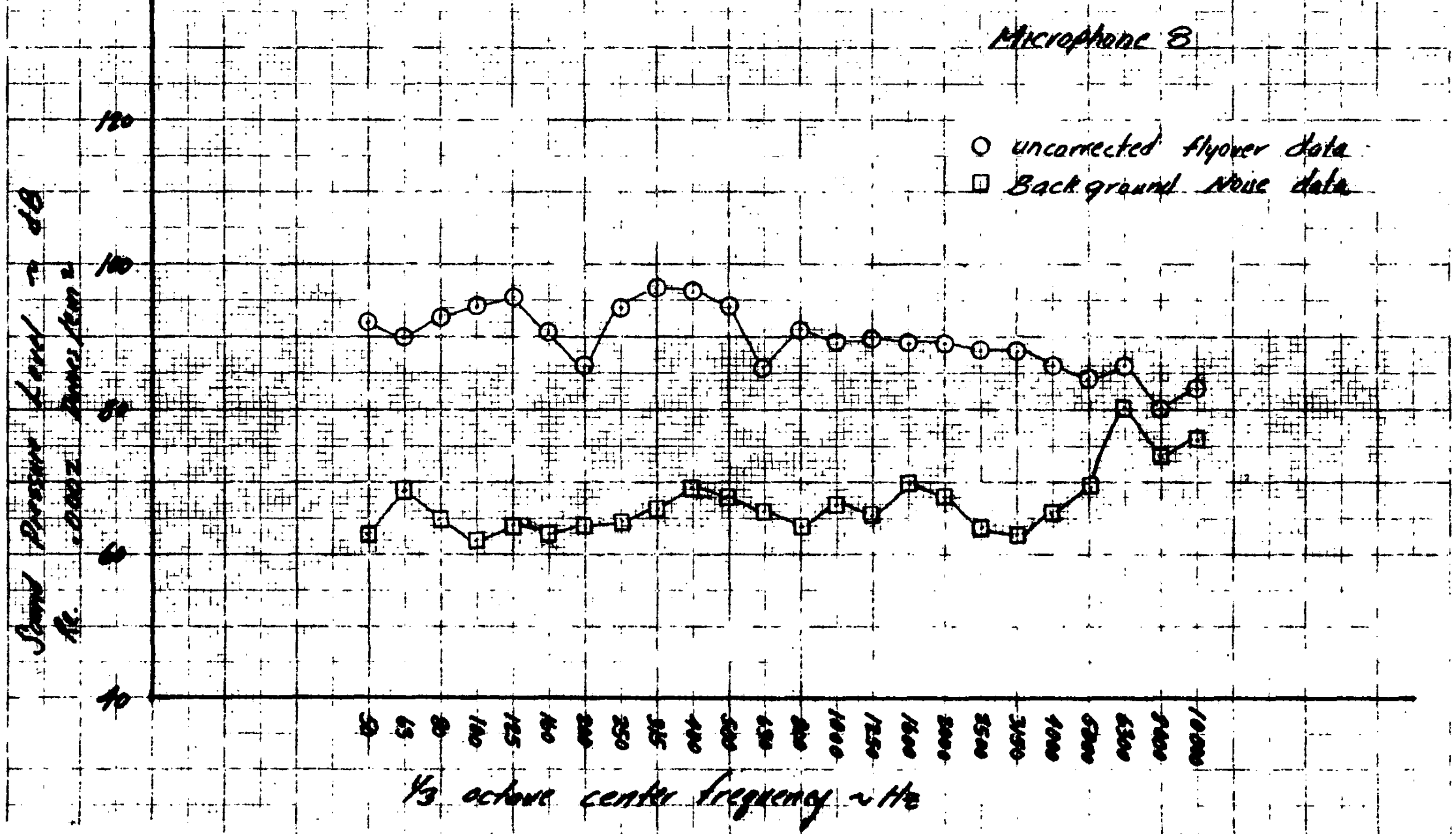


Figure 25.- Flyover Noise.

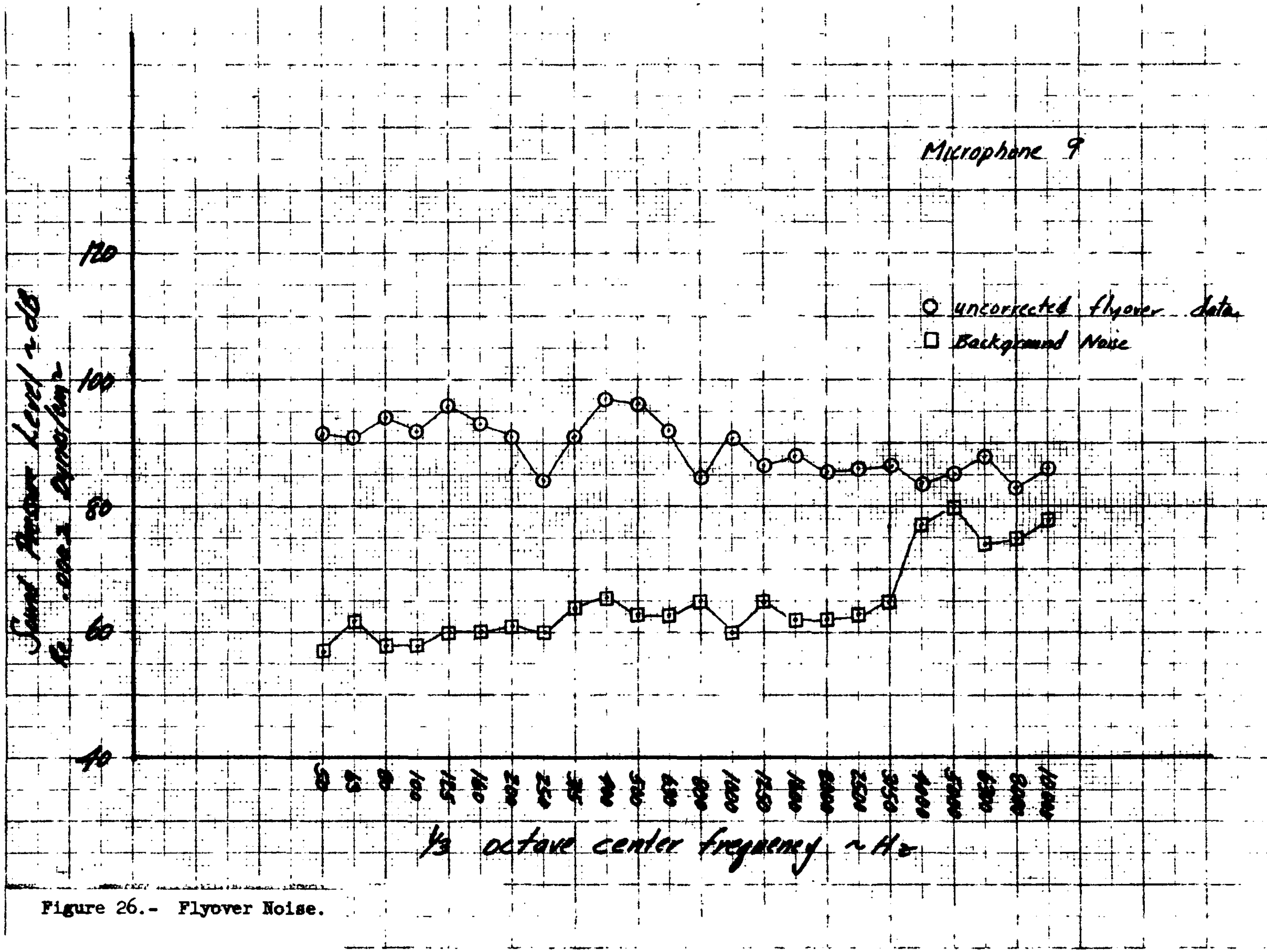


Figure 26.- Flyover Noise.

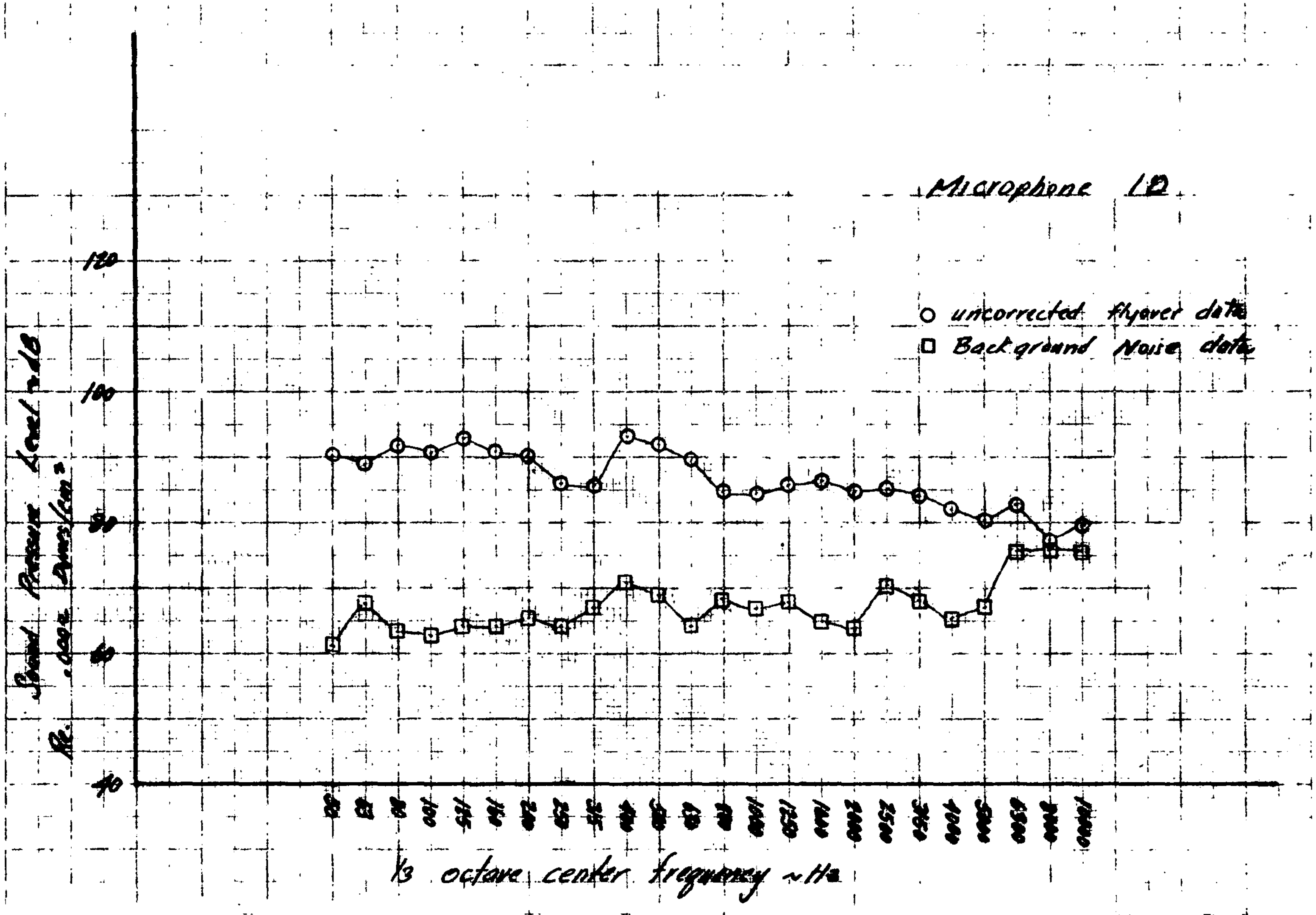


Figure 27.- Flyover Noise.

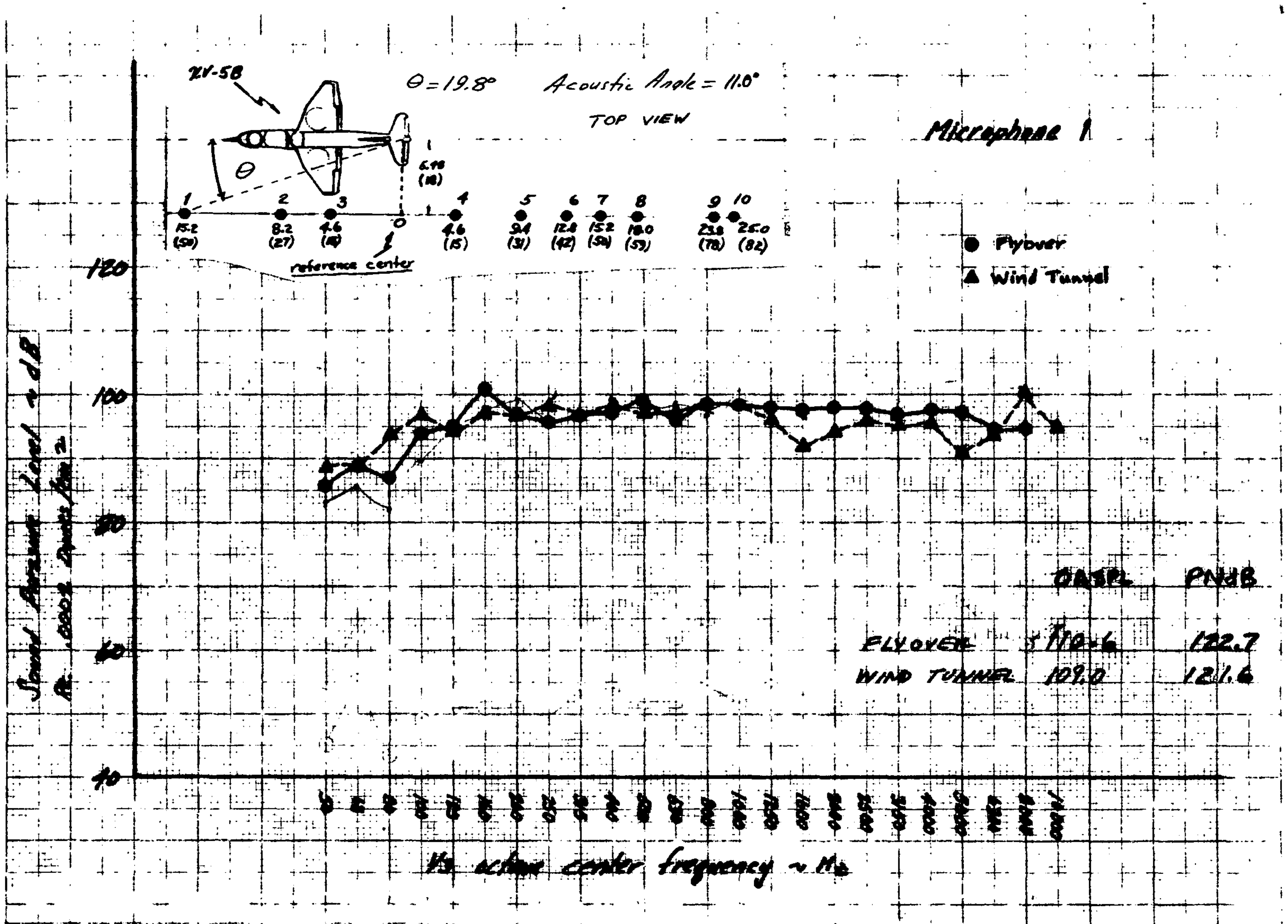


Figure 28. - Comparison of Wind Tunnel Noise Data to Flyover Noise Data.

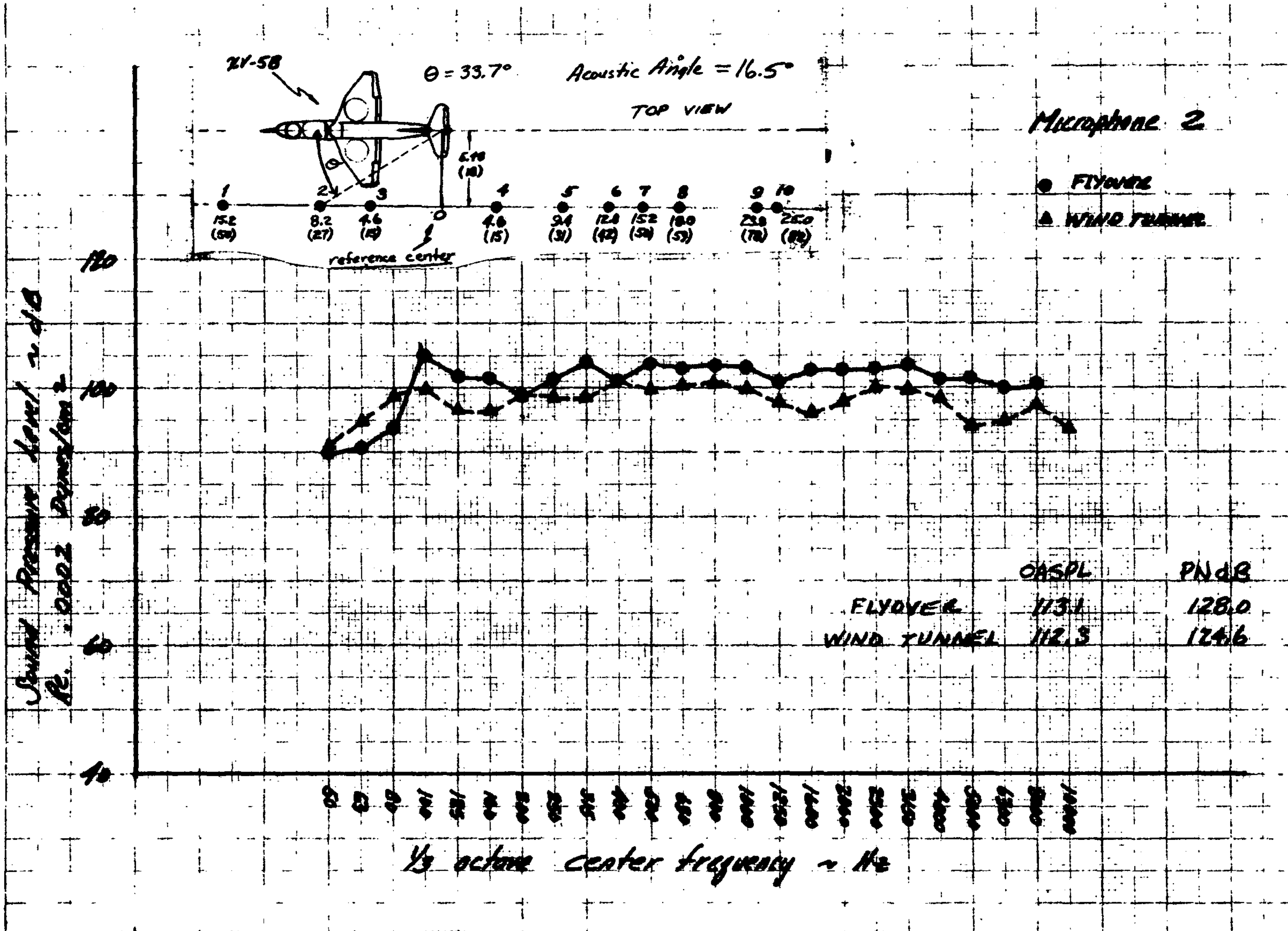


Figure 29.- Comparison of Wind Tunnel Noise Data to Flyover Noise Data.

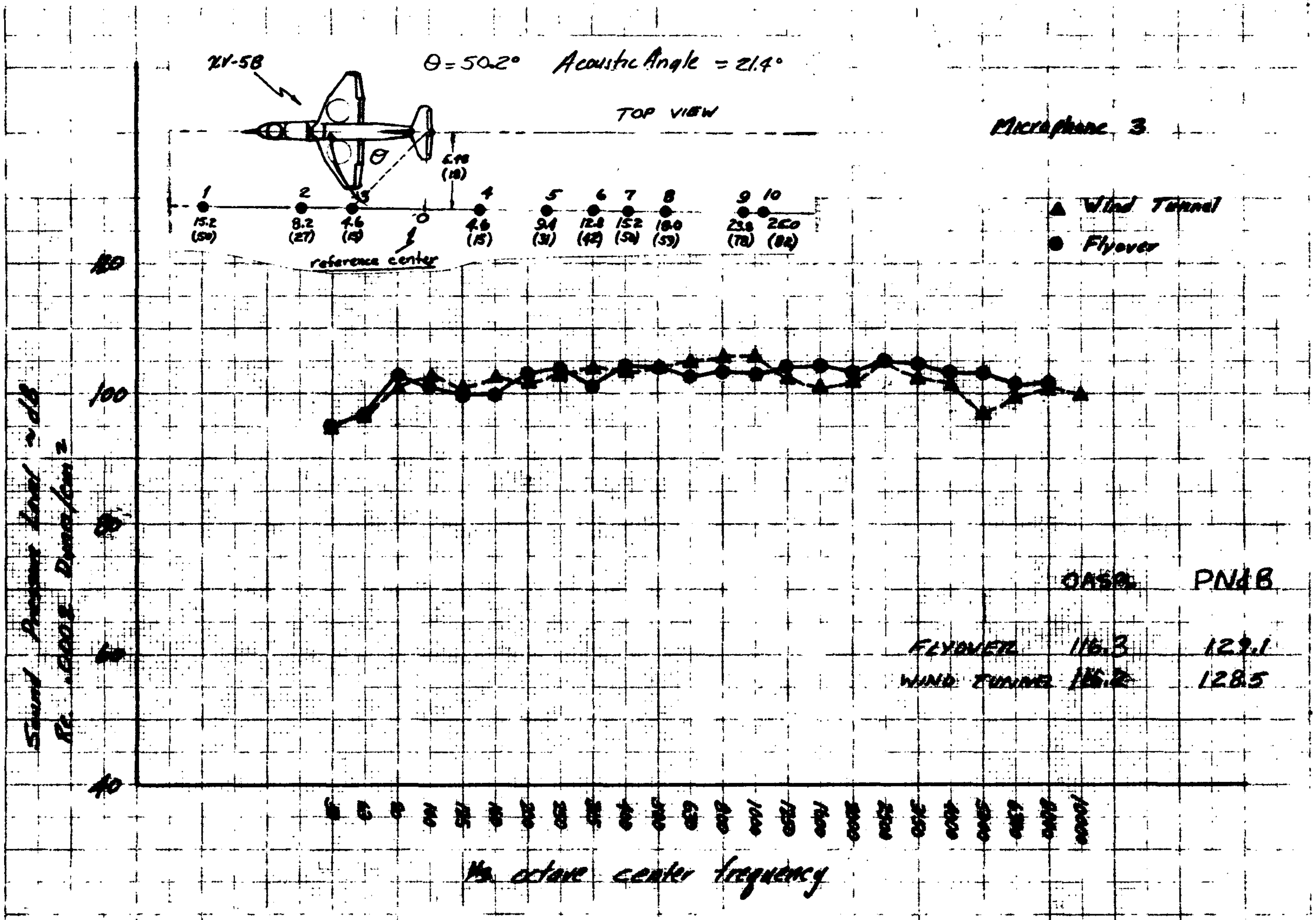


Figure 30. - Comparison of Wind Tunnel Noise Data to Flyover Noise Data.

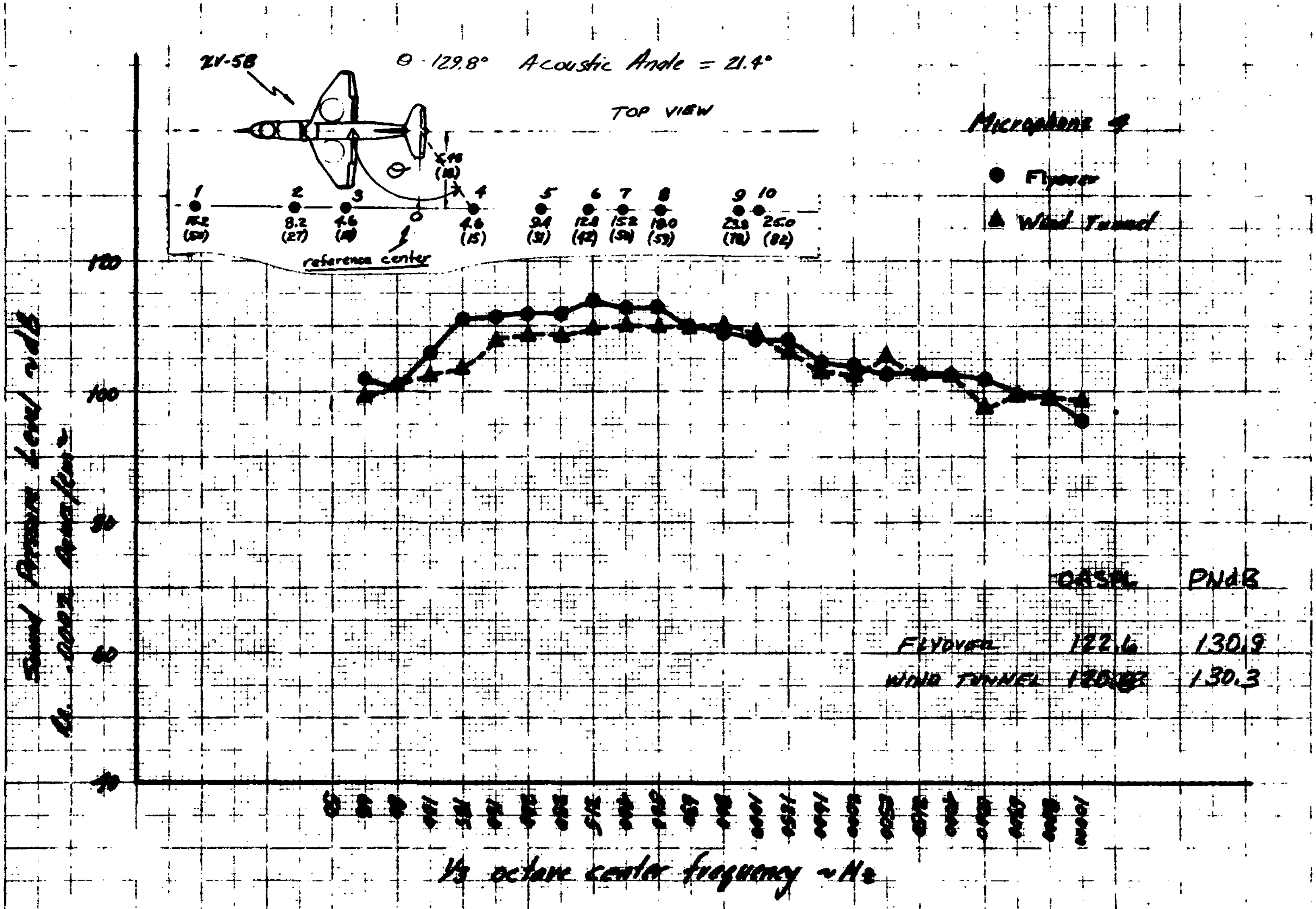


Figure 31.- Comparison of Wind Tunnel Noise Data to Flyover Noise Data.

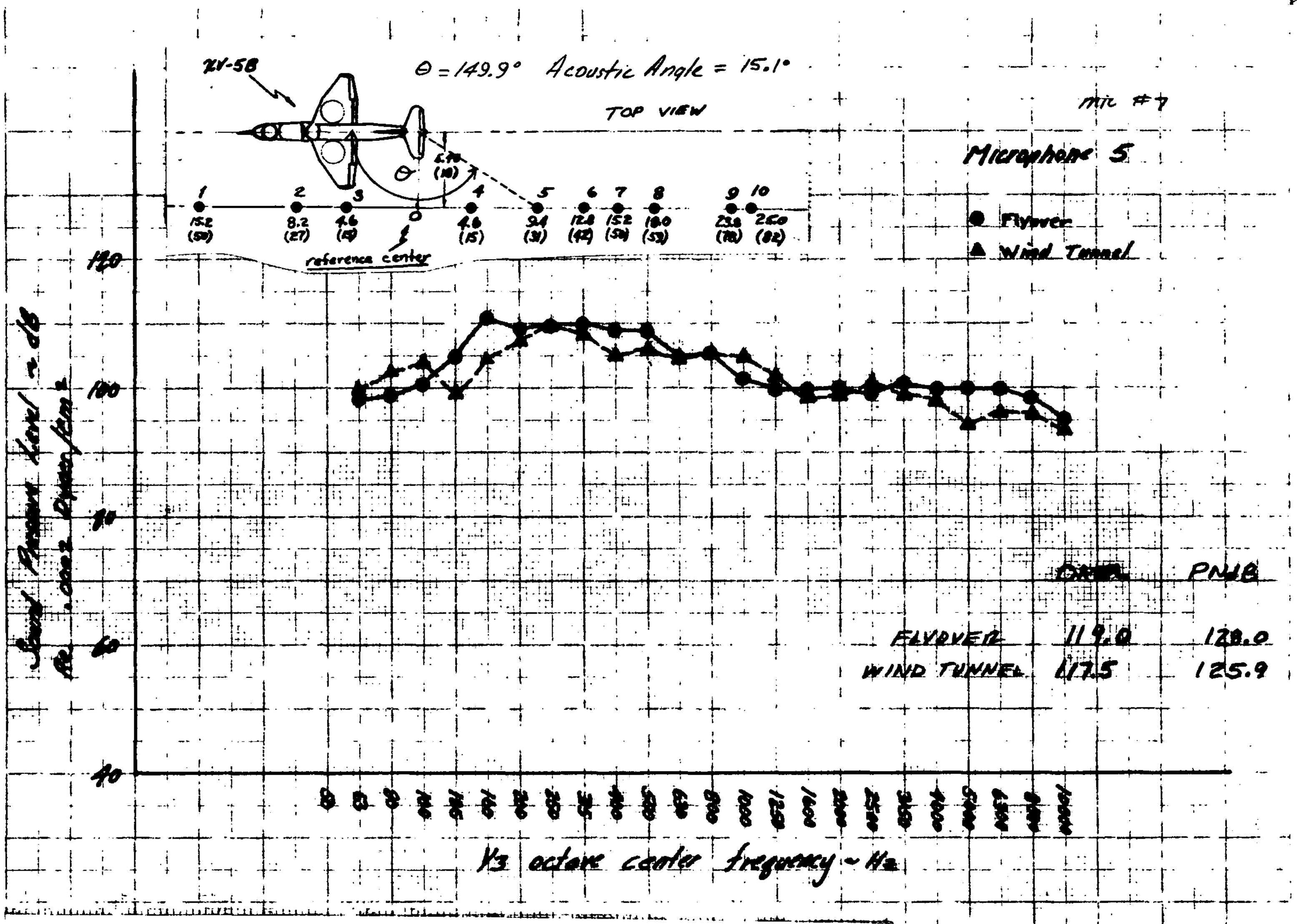


Figure 32. - Comparison of Wind Tunnel Noise Data to Flyover Noise Data.

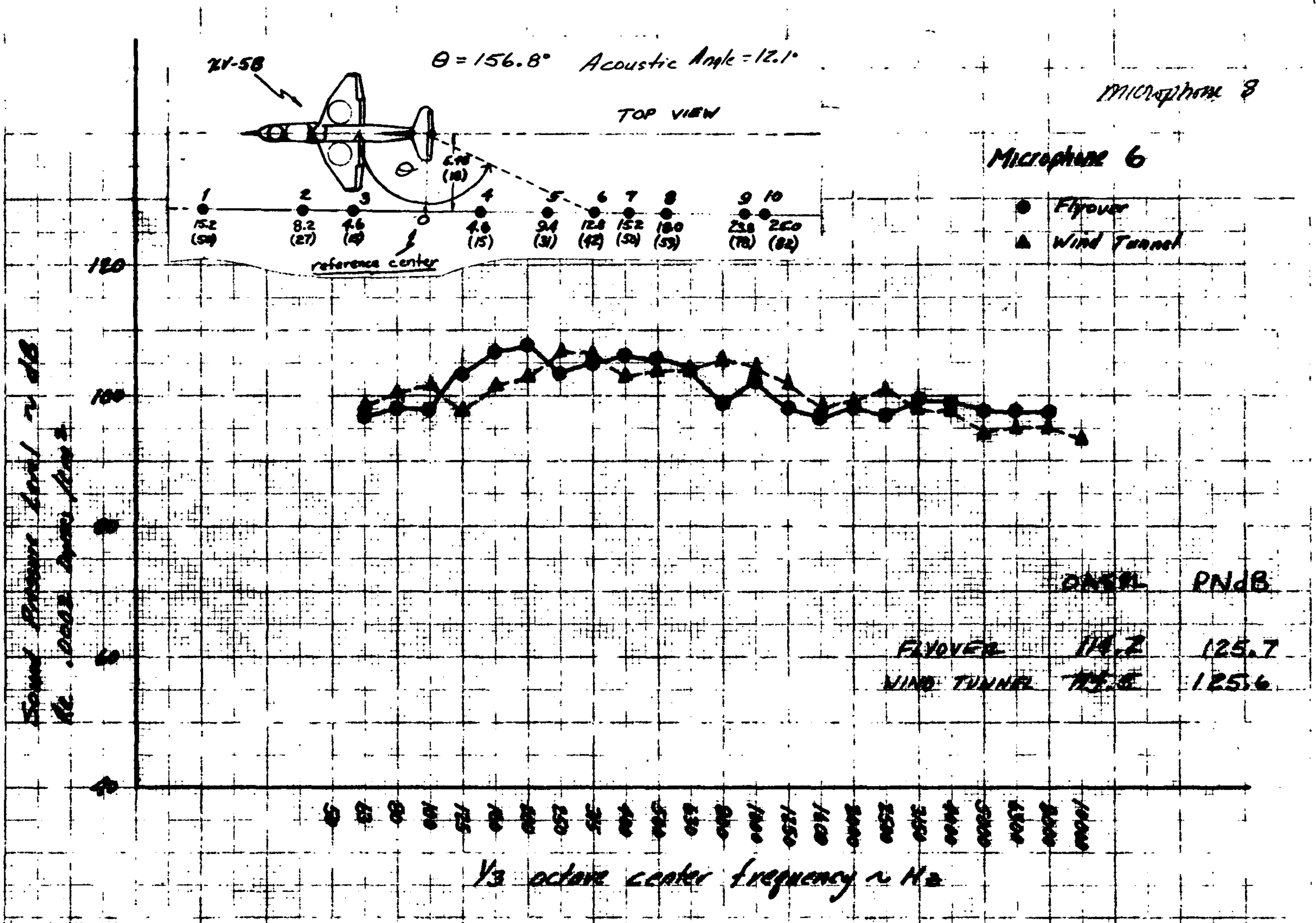
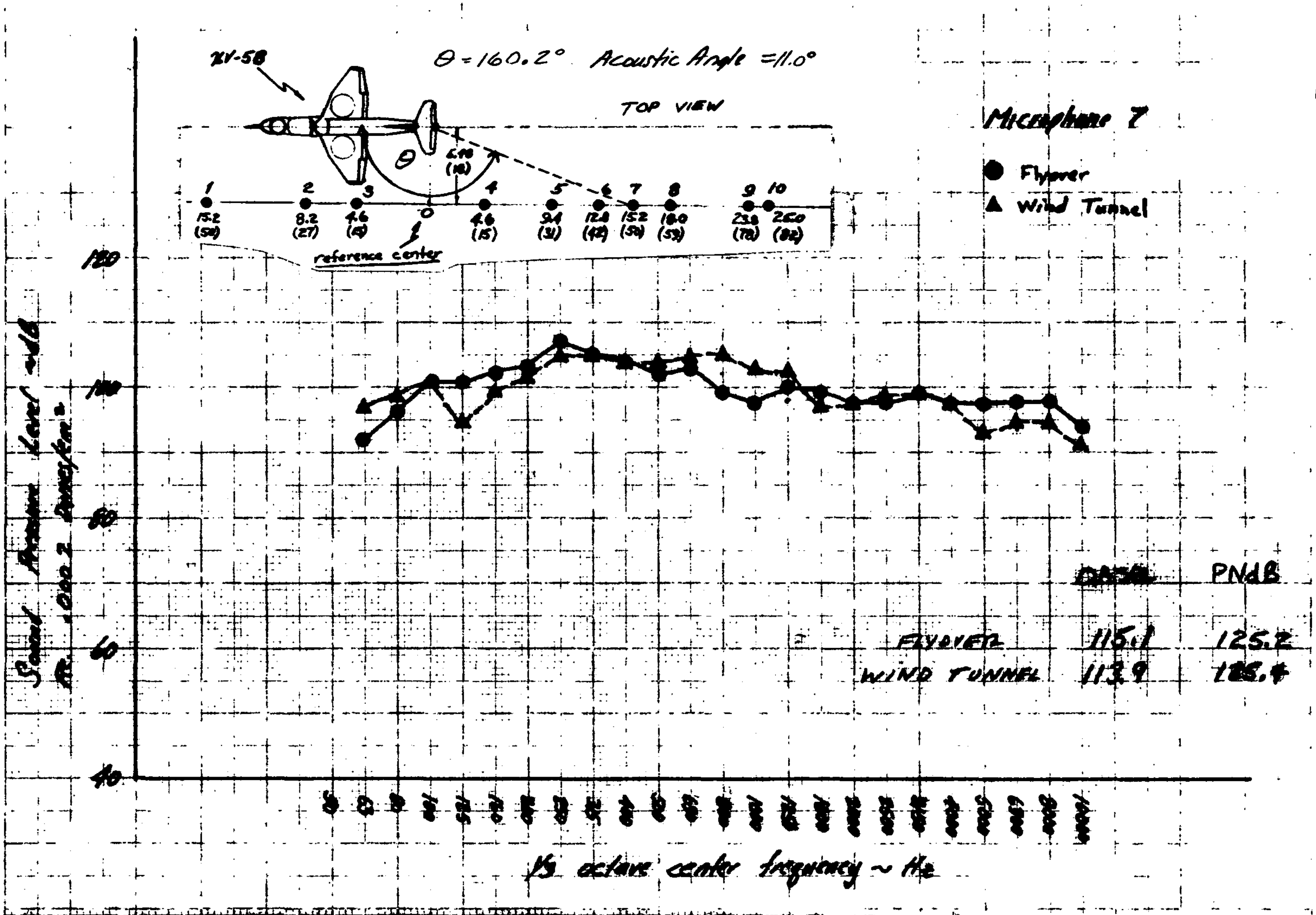


Figure 33. - Comparison of Wind Tunnel Noise Data to Flyover Noise Data.



mic 9
WT

Figure 34. - Comparison of Wind Tunnel Noise Data to Flyover Noise Data.

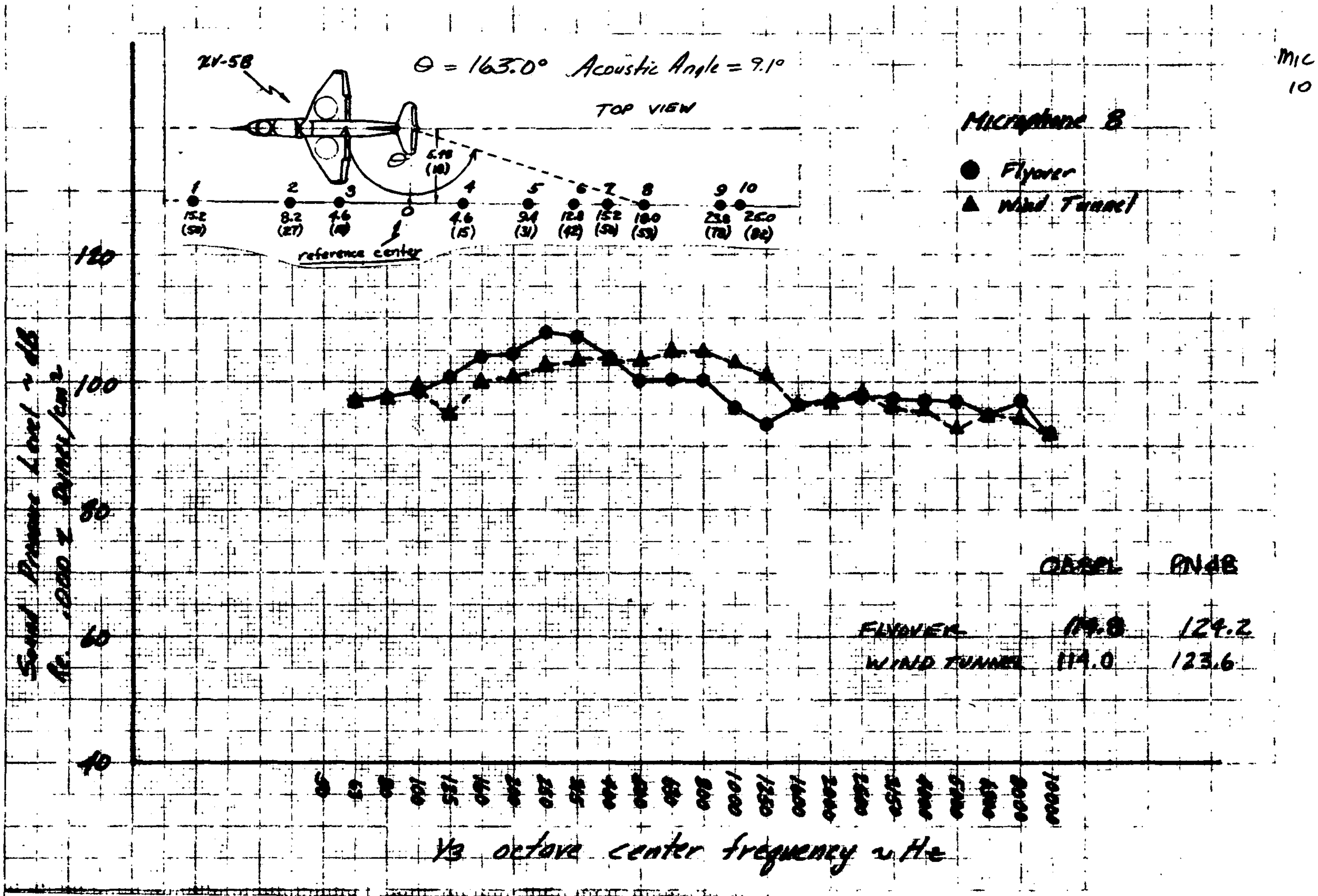
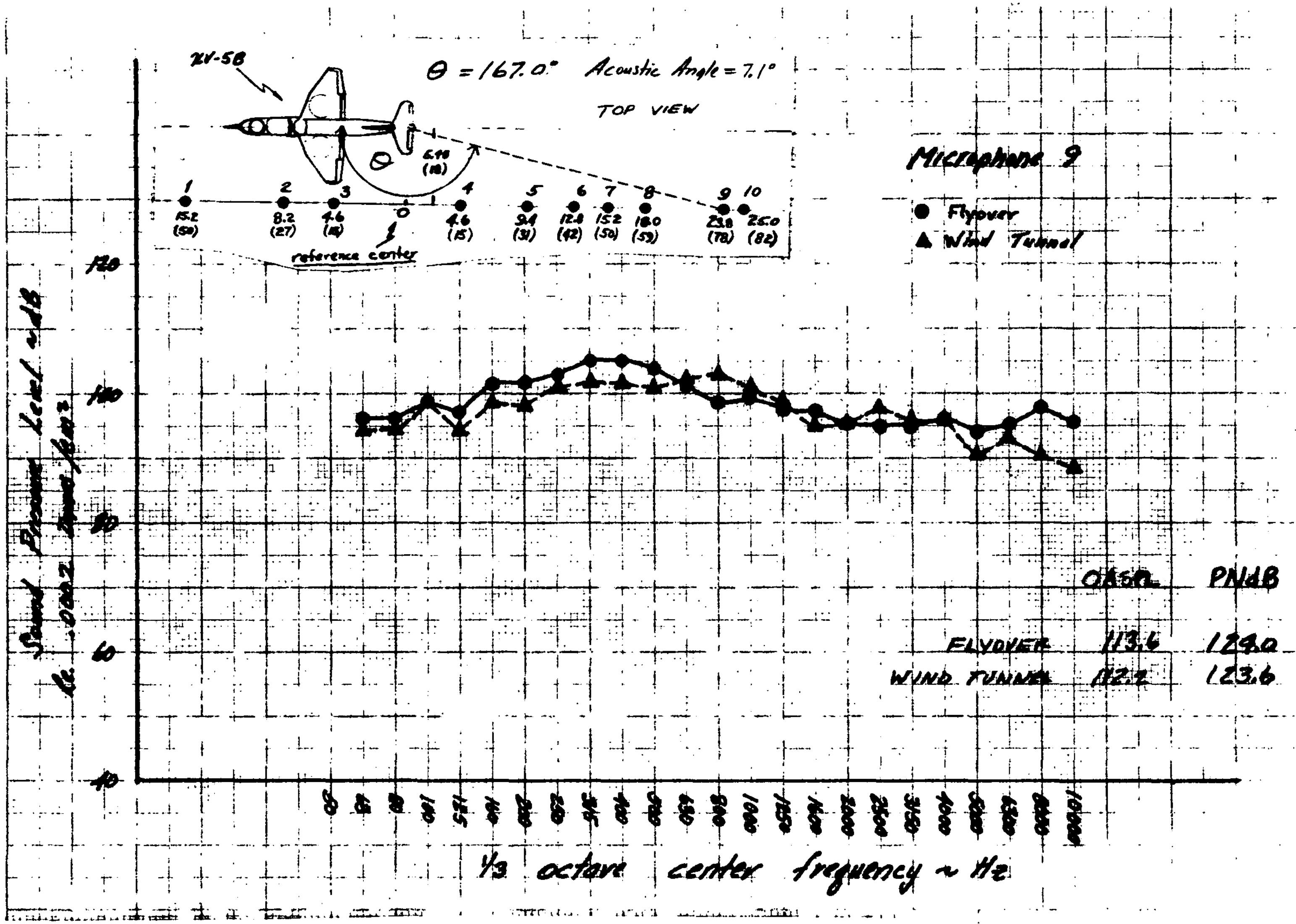


Figure 35.- Comparison of Wind Tunnel Noise Data to Flyover Noise Data.



mic 11

Figure 36. - Comparison of Wind Tunnel Noise Data to Flyover Noise Data.

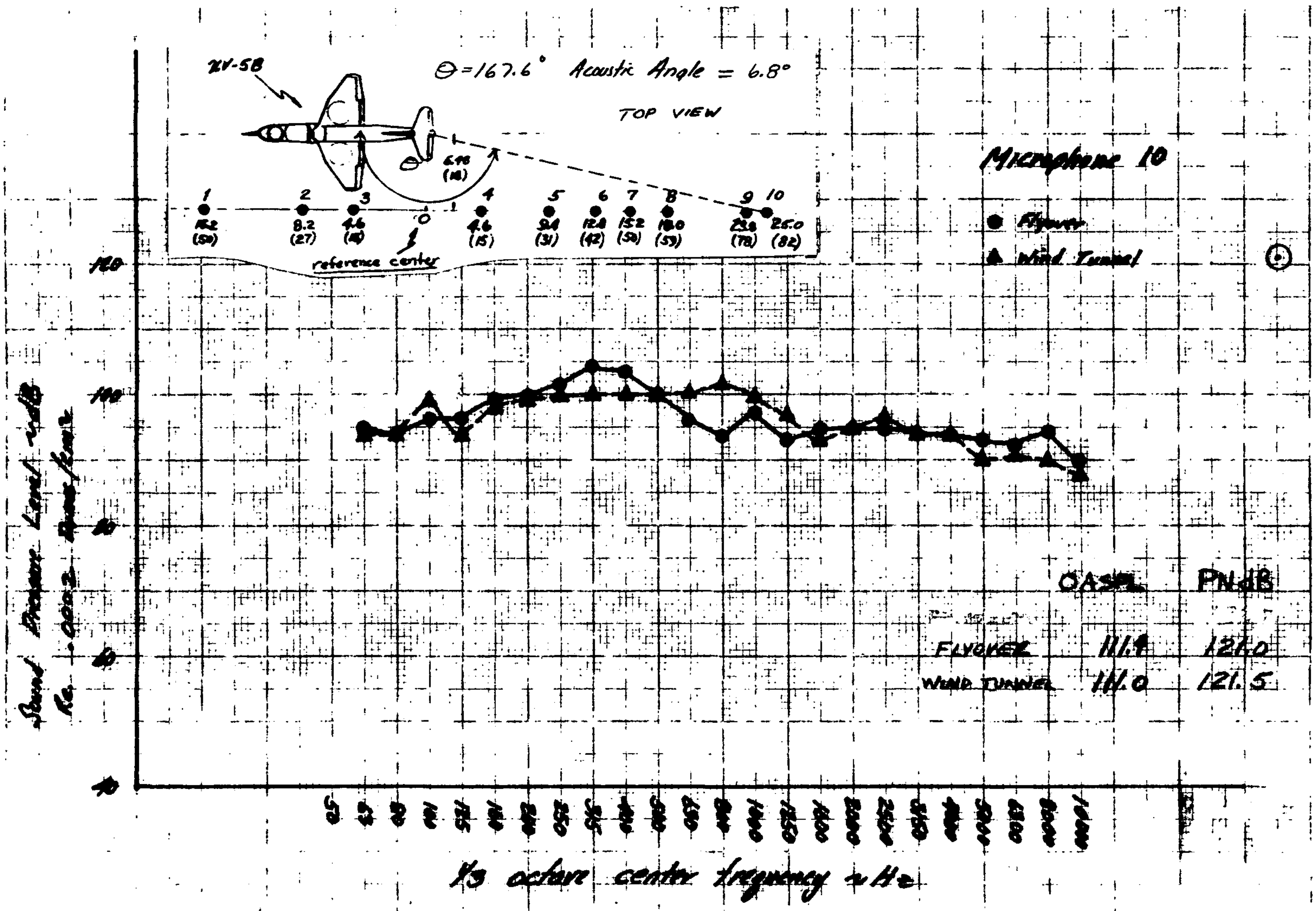


Figure 37. - Comparison of Wind Tunnel Noise Data to Flyover Noise Data.